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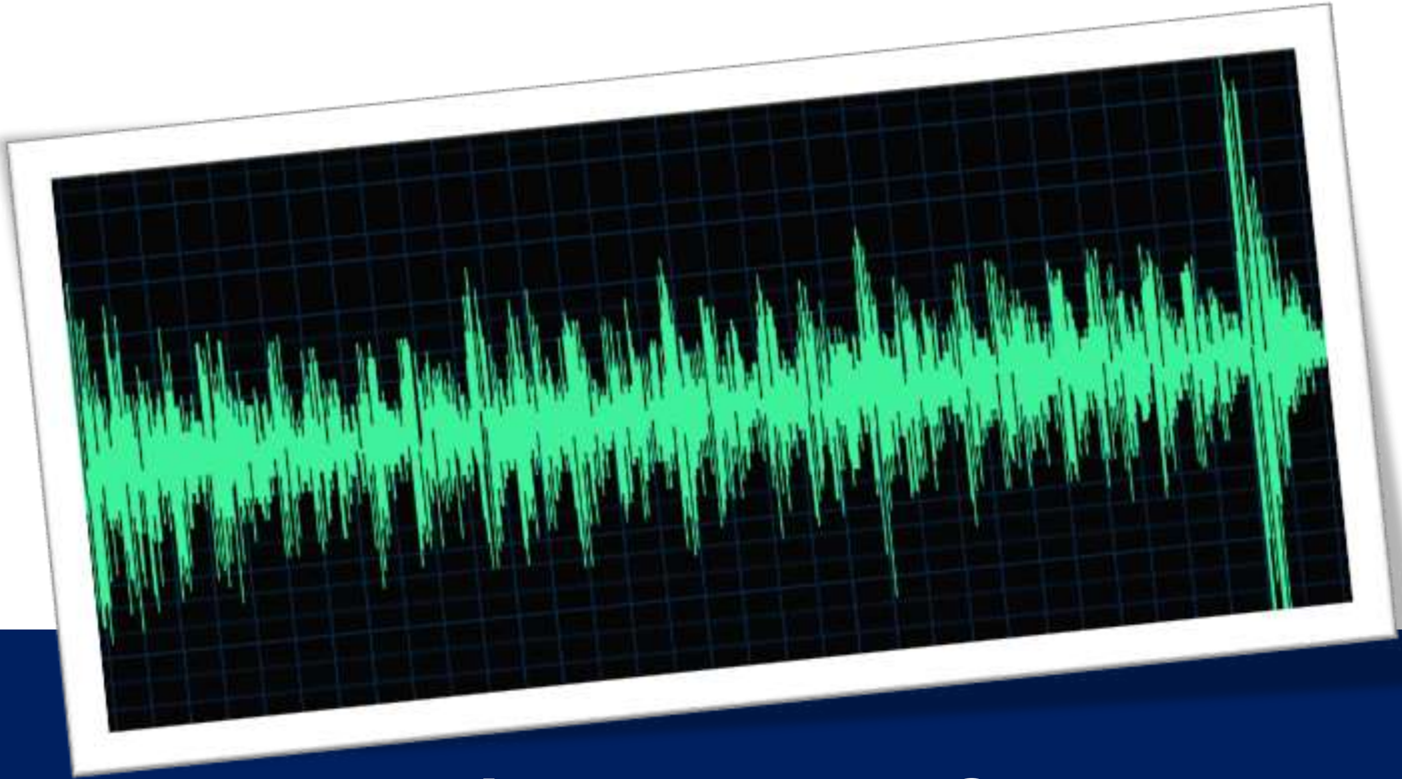

Lecture 8

Wave and Sound for Life and Health

10 October 2018

Wannapong Triampo, Ph.D.

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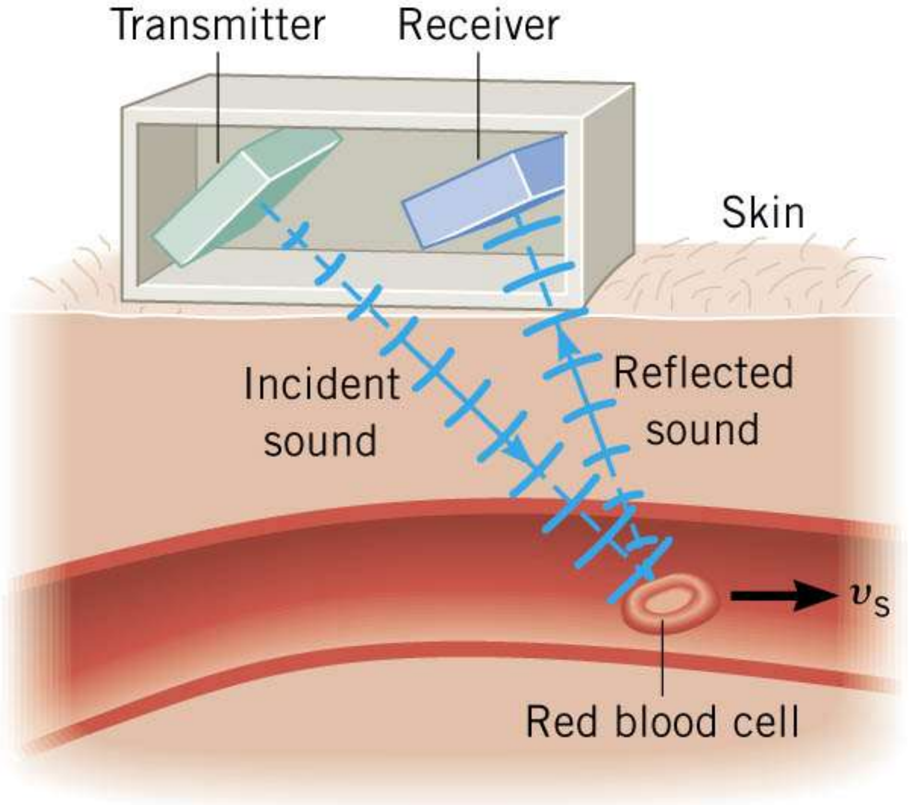
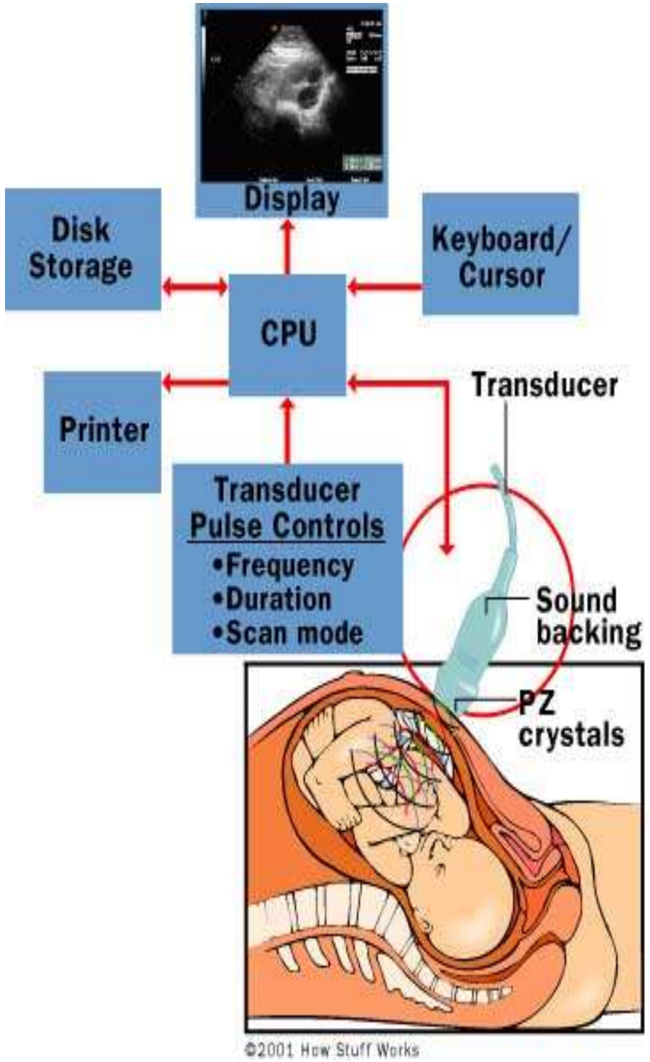
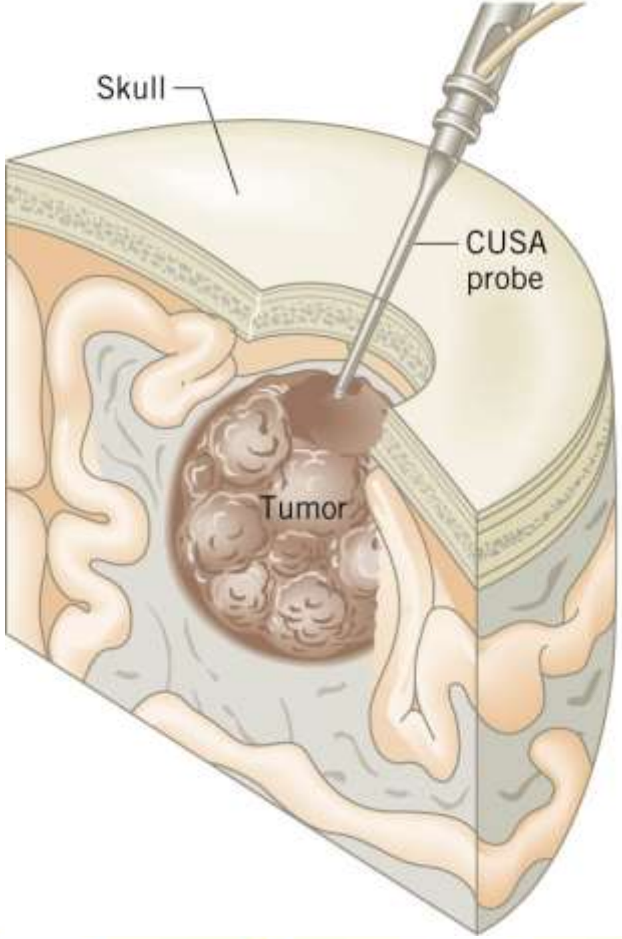


A Doppler flow meter measures the speed of red blood cells

Ultrasonography- detectionpe of foetus in uterus





Neurosurgeons use a cavitron ultrasonic surgical aspirator (CUSA) to “cut out” brain tumors without adversely affecting the surrounding healthy tissue.

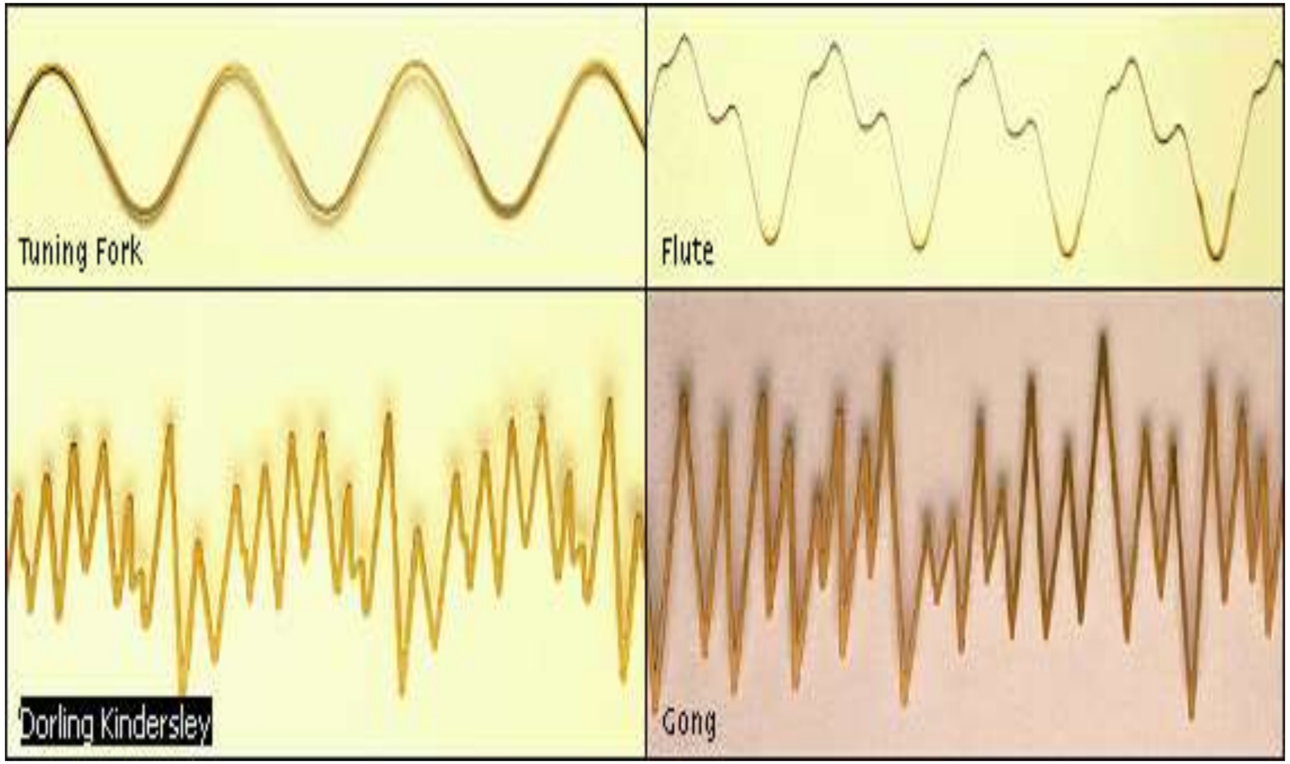
The Nature of Waves

Water waves have two features common to all waves:

1. A wave is a traveling disturbance.

2. A wave carries energy from place to place.

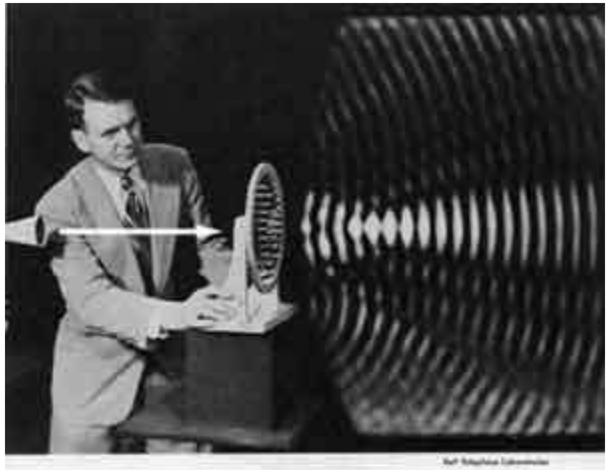
Sound Waves



- Each Sound wave has unique pattern
  - Frequency
  - Wavelength
  - Amplitude

What is a wave

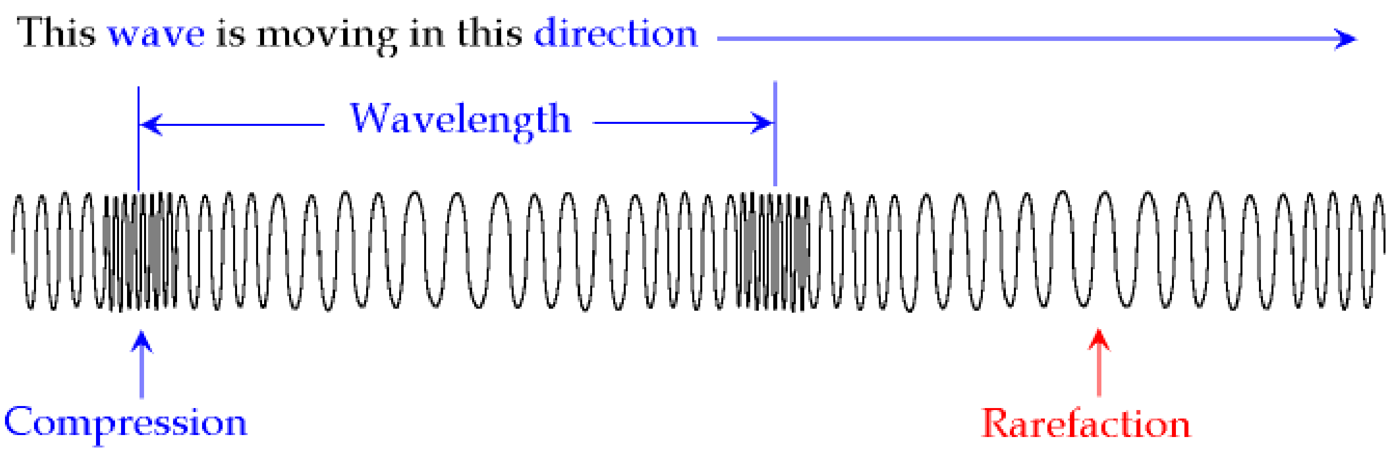
A WAVE is a vibration or disturbance in space.



A **MEDIUM** is the substance that all SOUND WAVES travel through and need to have in order to move.

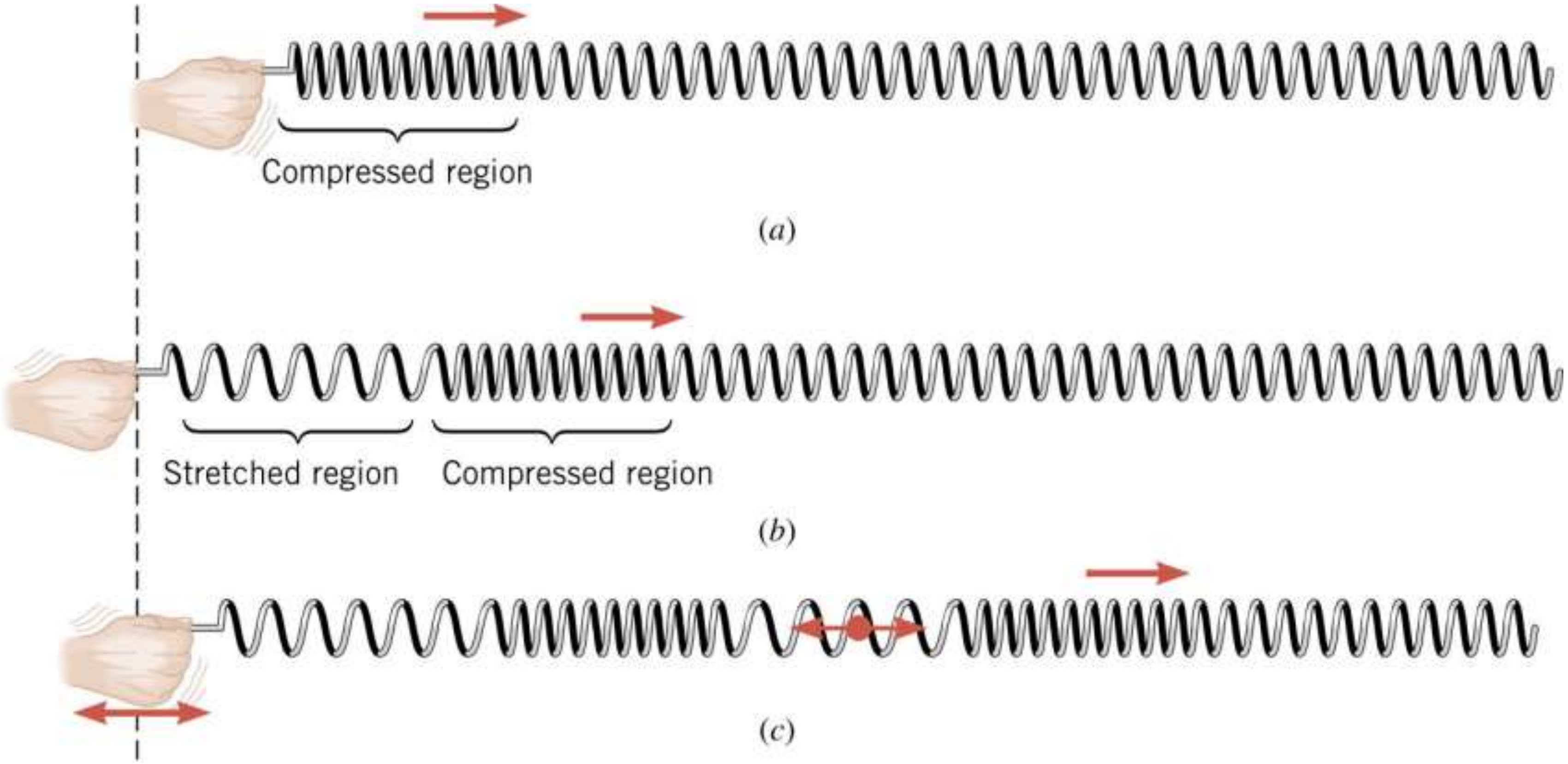
Two types of Waves

The first type of wave is called Longitudinal.



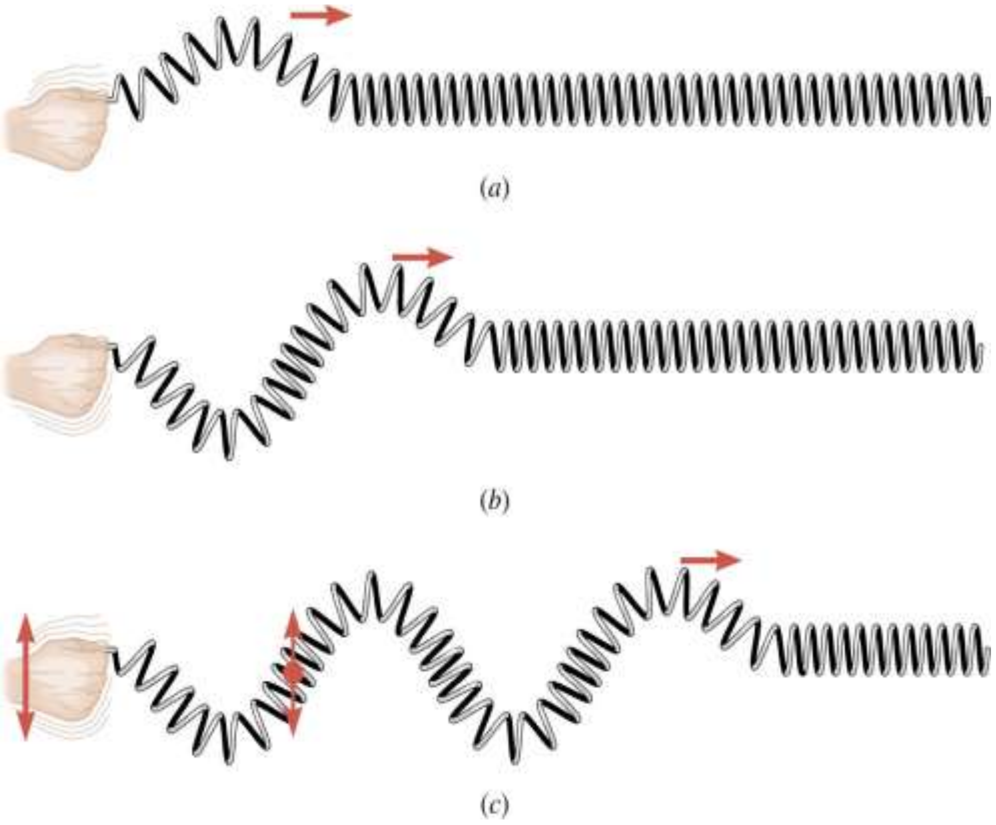
Longitudinal Wave - A fixed point will move parallel with the wave motion

2 areas
Compression- an area of high molecular density and pressure
Rarefaction - an area of low molecular density and pressure



A longitudinal wave is one in which the disturbance occurs parallel to the line of travel of the wave.

A sound wave is a longitudinal wave.



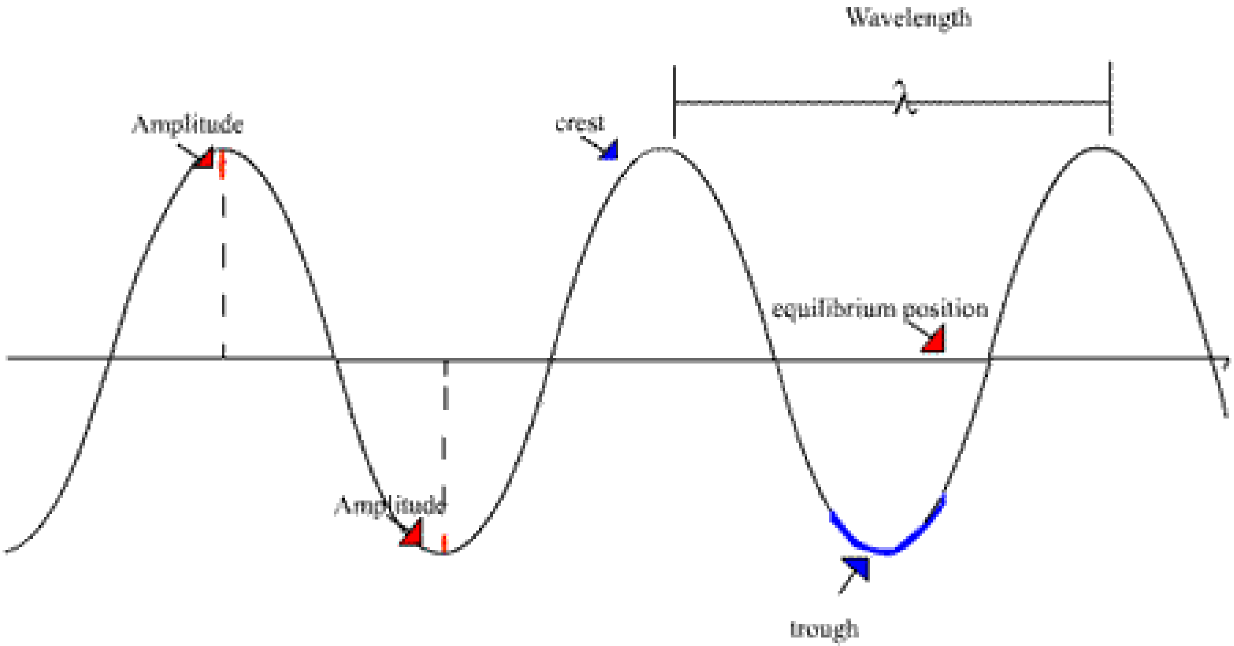
Two basic types of waves, transverse and longitudinal.

A transverse wave is one in which the disturbance occurs perpendicular to the direction of travel of the wave.

Radio waves, light waves, and microwaves are transverse waves. Transverse waves also travel on the strings of instruments such as guitars and banjos.

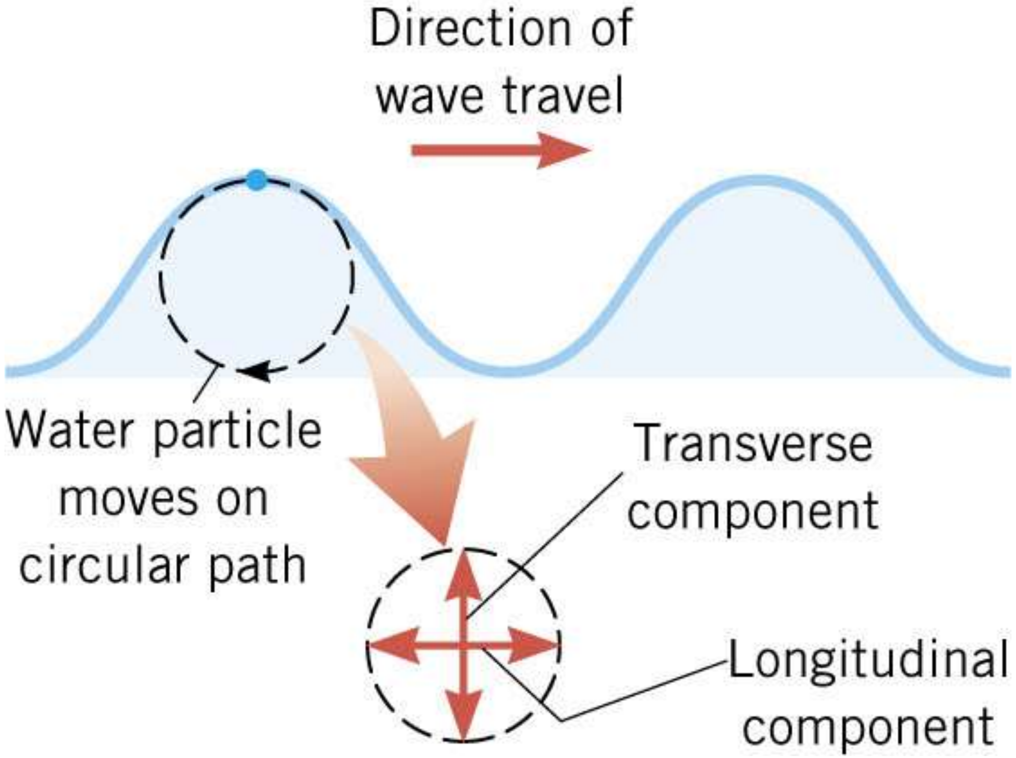
Two types of Waves

The second type of wave is called **Transverse**.



Transverse Wave - A fixed point will move perpendicular with the wave motion.

Wave parts(recall demo for simple harmonic motion)- crest, trough, wavelength, amplitude, frequency, period

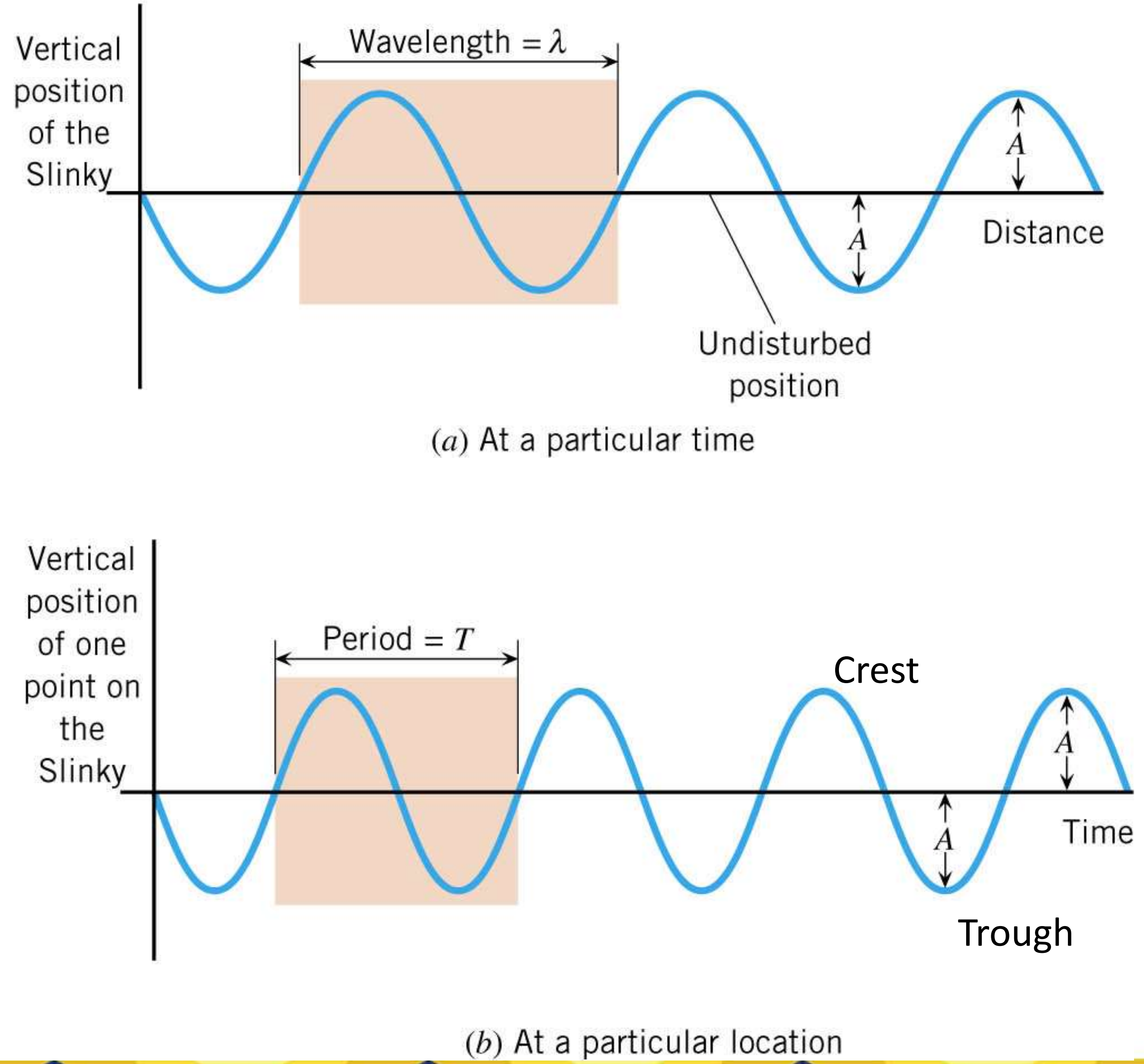


Some waves are neither transverse nor longitudinal.

A water wave is neither transverse nor longitudinal, since water particles at the surface move clockwise on nearly circular paths as the wave moves from left to right.

Periodic Waves

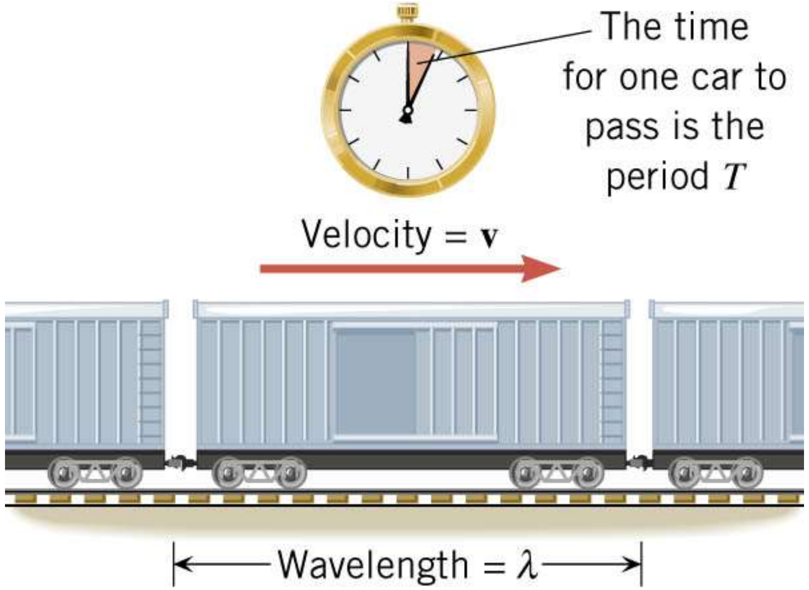
The transverse and longitudinal waves that we have been discussing are called *periodic waves* because they consist of cycles or patterns that are produced over and over again by the source.



Amplitude A **is the maximum excursion of a particle of the medium from the particle's undisturbed position.**

Wavelength λ **is the horizontal length of one cycle of the wave.**

Period T **is the time required for the wave to travel a distance of one wavelength. The period** ***T*** **is related to the** ***frequency f***



$$f = \frac{1}{T}$$

$$v = \frac{\lambda}{T} = f\lambda$$

These fundamental relations apply to longitudinal as well as to transverse waves.

Example 1. The Wavelengths of Radio Waves

AM and FM radio waves are transverse waves that consist of electric and magnetic disturbances. These waves travel at a speed of 3.00 $\times$ 10^8 m/s. A station broadcasts an AM radio wave whose frequency is 1230 $\times$ 10^3 Hz (1230 kHz on the dial) and an FM radio wave whose frequency is 91.9 $\times$ 10^6 Hz (91.9 MHz on the dial). Find the distance between adjacent crests in each wave.

AM $$\lambda = \frac{v}{f} = \frac{3.00\times10^{8}\ \text{m/s}}{1230\times10^{3}\ \text{Hz}} = \boxed{244\ \text{m}}$$

FM $$\lambda = \frac{v}{f} = \frac{3.00\times10^{8}\ \text{m/s}}{91.9\times10^{6}\ \text{Hz}} = \boxed{3.26\ \text{m}}$$

Example

A harmonic wave is traveling along a rope. It is observed that the oscillator that generates the wave completes 40.0 vibrations in 30.0 s. Also, a given maximum travels 425 cm along a rope in 10.0 s . What is the wavelength?

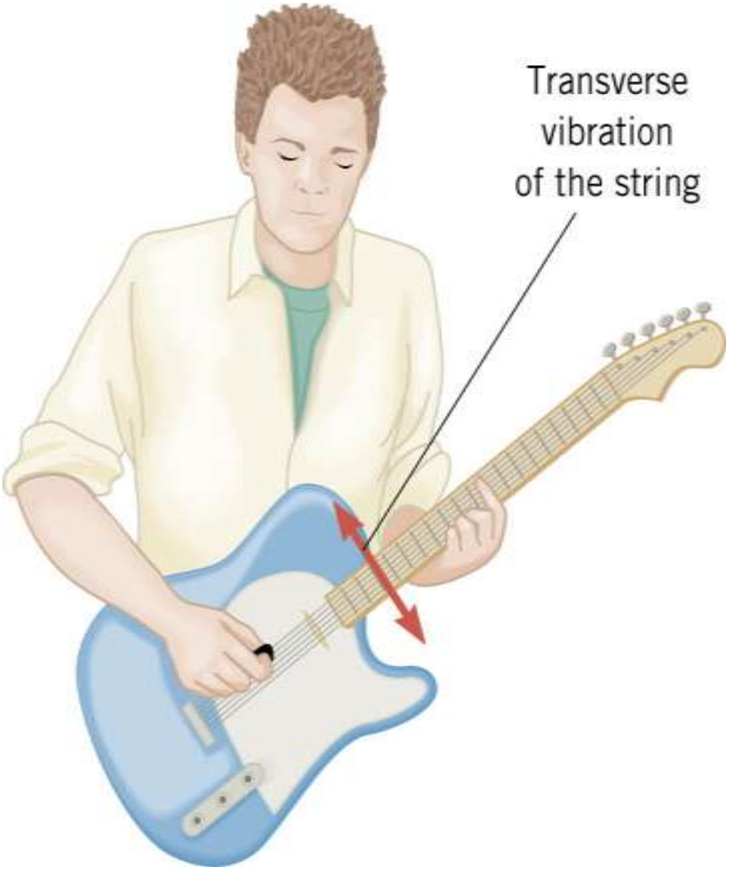
$$f = \frac{cycles}{\sec} = \frac{40}{30} = 1.33\,Hz$$

$$\bar{v} = \frac{\Delta x}{\Delta t} = \frac{0.425}{10} = 0.425\,m/s$$

$$v_{wave} = \lambda f \rightarrow \lambda = \frac{0.425}{1.33} =$$

0.0319 m/s

Example 2. Waves Traveling on Guitar Strings



Transverse waves travel on the strings of an electric guitar after the strings are plucked. The length of each string between its two fixed ends is 0.628 m, and the mass is 0.208 g for the highest pitched E string and 3.32 g for the lowest pitched E string. Each string is under a tension of 226 N. Find the speeds of the waves on the two strings.

High-pitched E

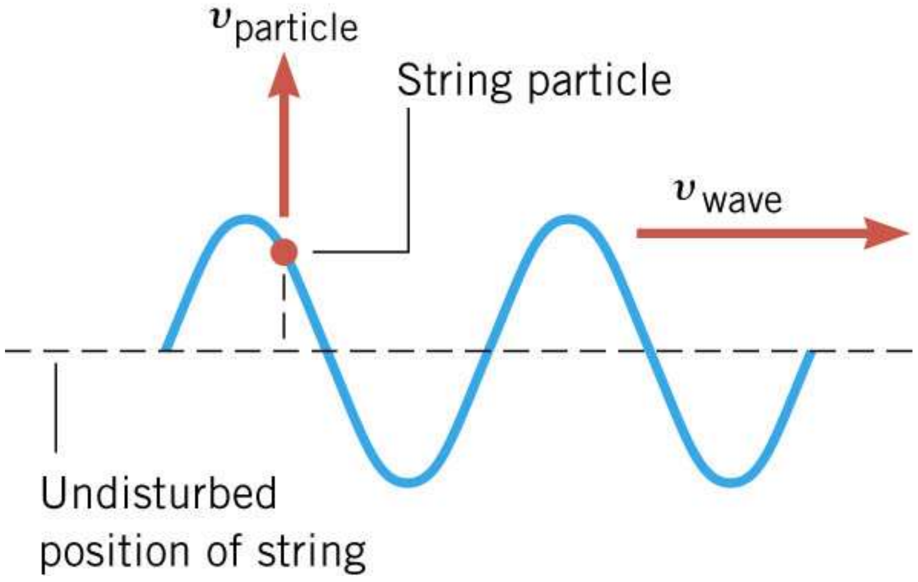
$$v = \sqrt{\frac{F}{m/L}} = \sqrt{\frac{226\ \text{N}}{(0.208 \times 10^{-3}\ \text{kg})/(0.628\ \text{m})}} = \boxed{826\ \text{m/s}}$$

Low-pitched E

$$v = \sqrt{\frac{F}{m/L}} = \sqrt{\frac{226\ \text{N}}{(3.32 \times 10^{-3}\ \text{kg})/(0.628\ \text{m})}} = \boxed{207\ \text{m/s}}$$

Conceptual Example 3.

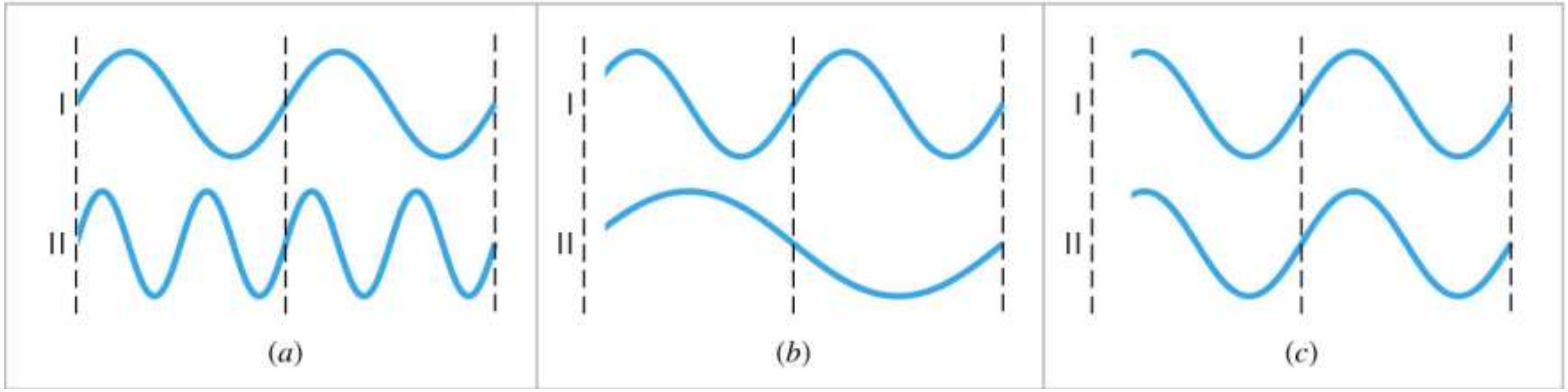
Wave Speed Versus Particle Speed



Is the speed of a transverse wave on a string the same as the speed at which a particle on the string moves ?

The two speeds, v_{wave} and $v_{particle}$, are not the same.

Check Your Understanding 1



String I and string II have the same length. However, the mass of string I is twice the mass of string II, and the tension in string I is eight times the tension in string II. A wave of the same amplitude and frequency travels on each of these strings. Which of the pictures in the drawing correctly shows the waves?

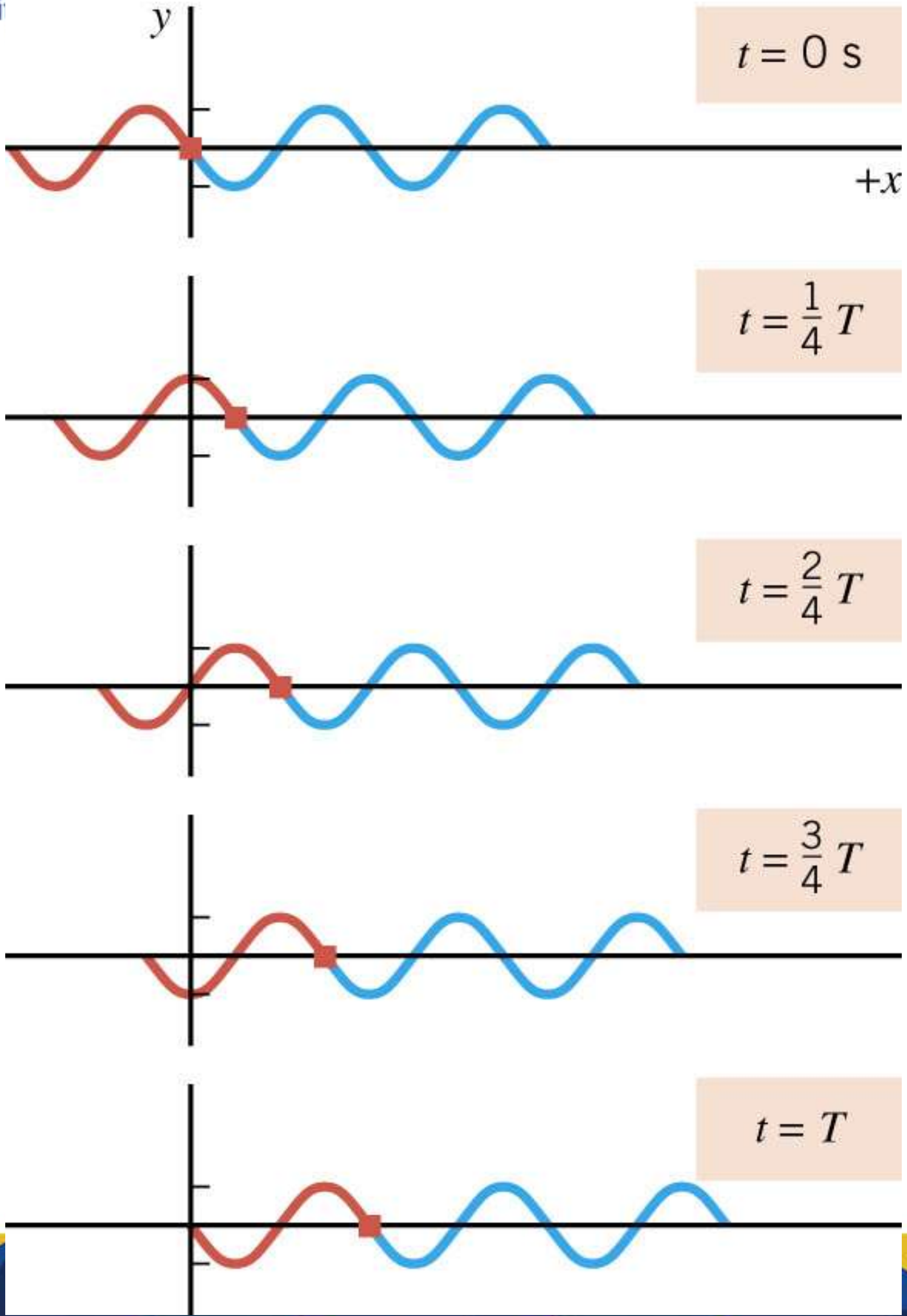
(a)

The Mathematical Description of a Wave

$$\textit{Wave motion toward } +x \qquad y = A\sin\left(2\pi f t - \frac{2\pi x}{\lambda}\right)$$

$$\textit{Wave motion toward } -x \qquad y = A\sin\left(2\pi f t + \frac{2\pi x}{\lambda}\right)$$

$$2\pi f t - \frac{2\pi x}{\lambda} = 2\pi f\left(t - \frac{x}{f\lambda}\right) = 2\pi f\left(t - \frac{x}{v}\right)$$



The figure shows a series of times separated by one-fourth of the period *T*. The colored square in each graph marks the place on the wave that is located at *x* = 0 m when *t* = 0 s. As time passes, the wave moves to the right.

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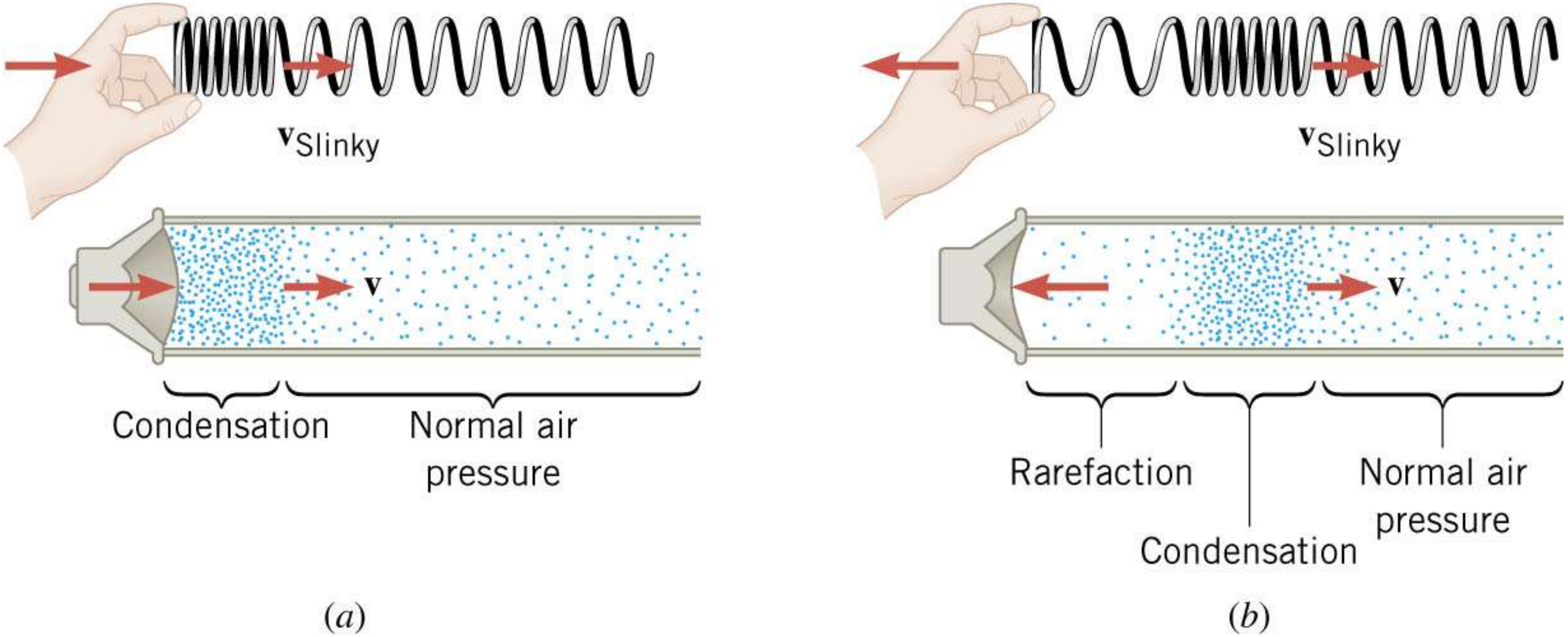
The Nature of Sound

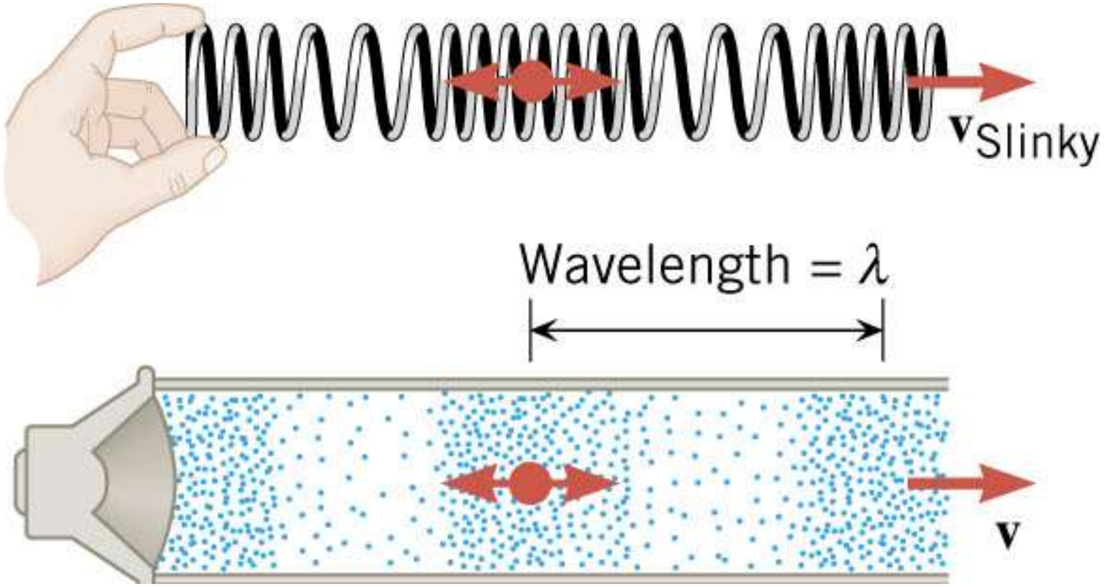
Longitudinal Sound Waves

Sound **is a longitudinal wave that is created by a vibrating object. It can be created or transmitted only in a medium and cannot exist in a vacuum.**

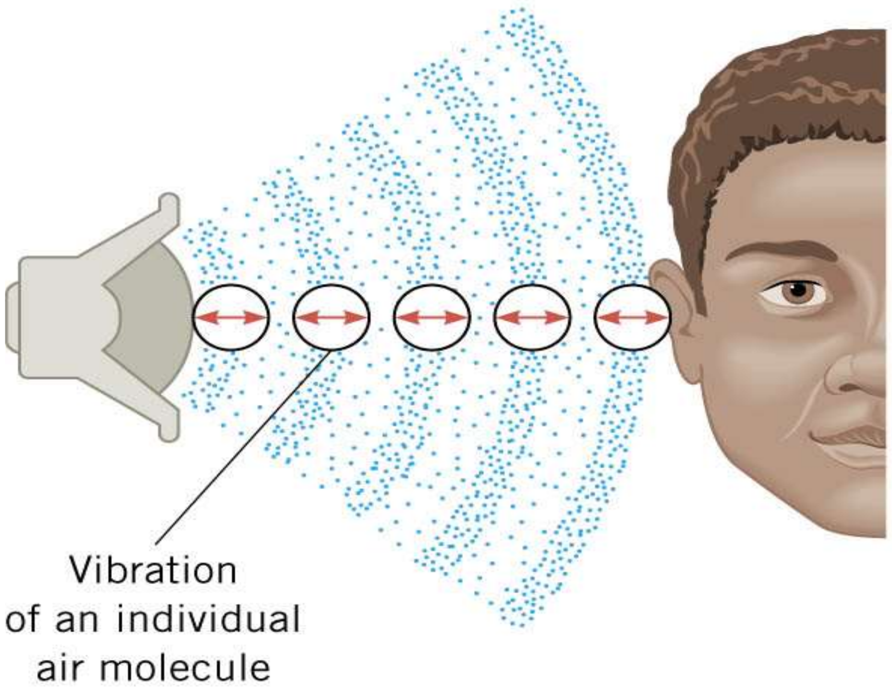
The region of increased pressure is called a ***condensation***.

The inward motion produces a region known as a ***rarefaction***, where the air pressure is slightly less than normal.





Both the wave on the Slinky and the sound wave are longitudinal. The colored dots attached to the Slinky and to an air molecule vibrate back and forth parallel to the line of travel of the wave.

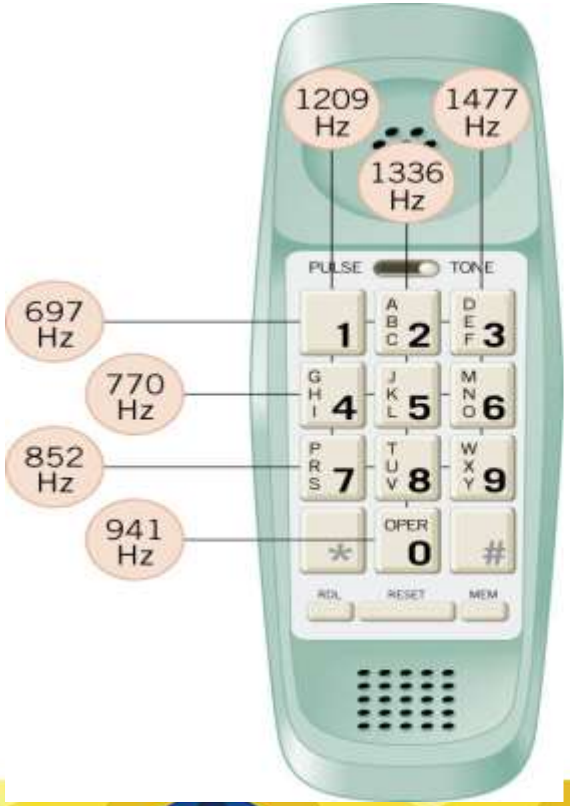


Condensations and rarefactions travel from the speaker to the listener, but the individual air molecules do not move with the wave. A given molecule vibrates back and forth about a fixed location.

The Frequency of A Sound Wave

Frequency **is the number of cycles per second that passes by a given location.**

A sound with a single frequency is called a *pure tone*.



Pure tones are used in push-button telephones.

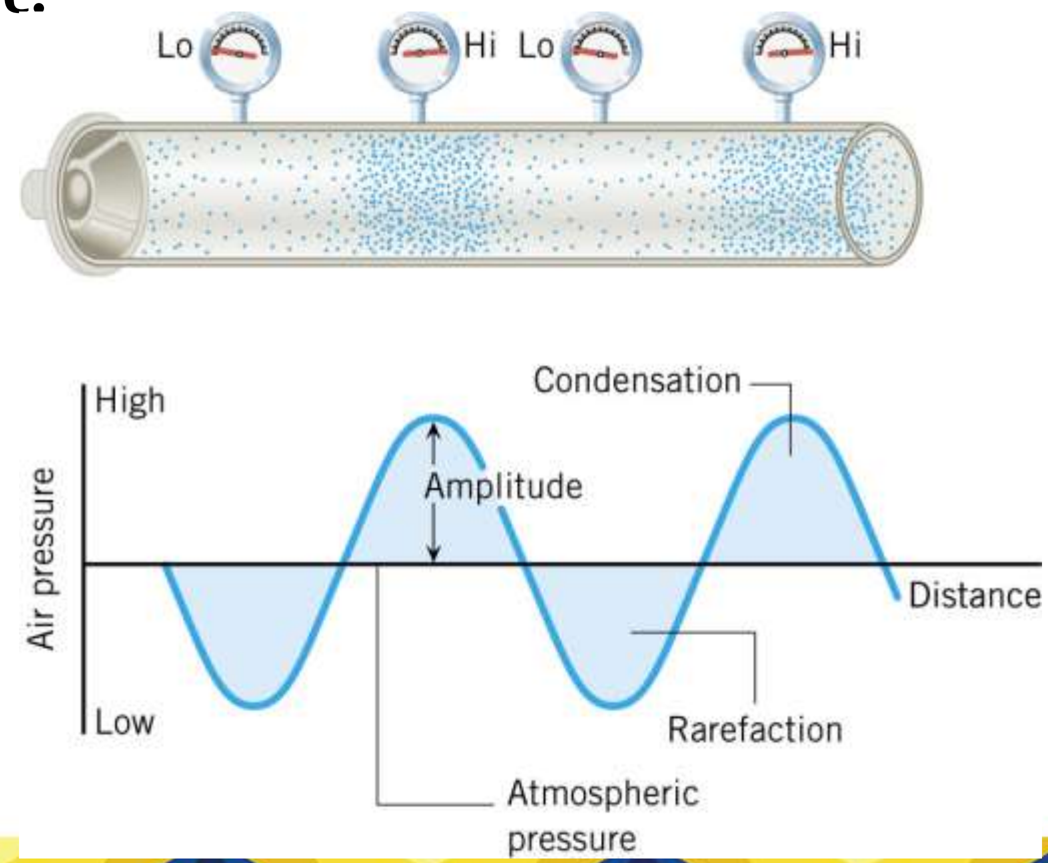
Sound waves with frequencies below 20 Hz are said to be *infrasonic*, while those with frequencies above 20 kHz are referred to as *ultrasonic*.

Rhinoceroses use infrasonic frequencies as low as 5 Hz to call one another, while bats use ultrasonic frequencies up to 100 kHz for locating their food sources and navigating.

The brain interprets the frequency detected by the ear primarily in terms of the subjective quality called *pitch*.

The Pressure Amplitude of A Sound Wave

Pressure amplitude **is the magnitude of the maximum change in pressure, measured relative to the undisturbed or atmospheric pressure.**



Loudness **is an attribute of sound that depends primarily on the amplitude of the wave: the larger the amplitude, the louder the sound.**

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The Speed of Sound

Substance	Speed (m/s)	Substance	Speed (m/s)
Gases		*Liquids*	
Air (0 ° C)	331	Chloroform (20 ° C)	1004
Air (20 ° C)	343	Ethyl alcohol (20 ° C)	1162
Carbon dioxide (0 ° C)	259	Mercury (20 ° C)	1450
Oxygen (0 ° C)	316	Fresh water (20 ° C)	1482
Helium (0 ° C)	965	Seawater (20 ° C)	1522

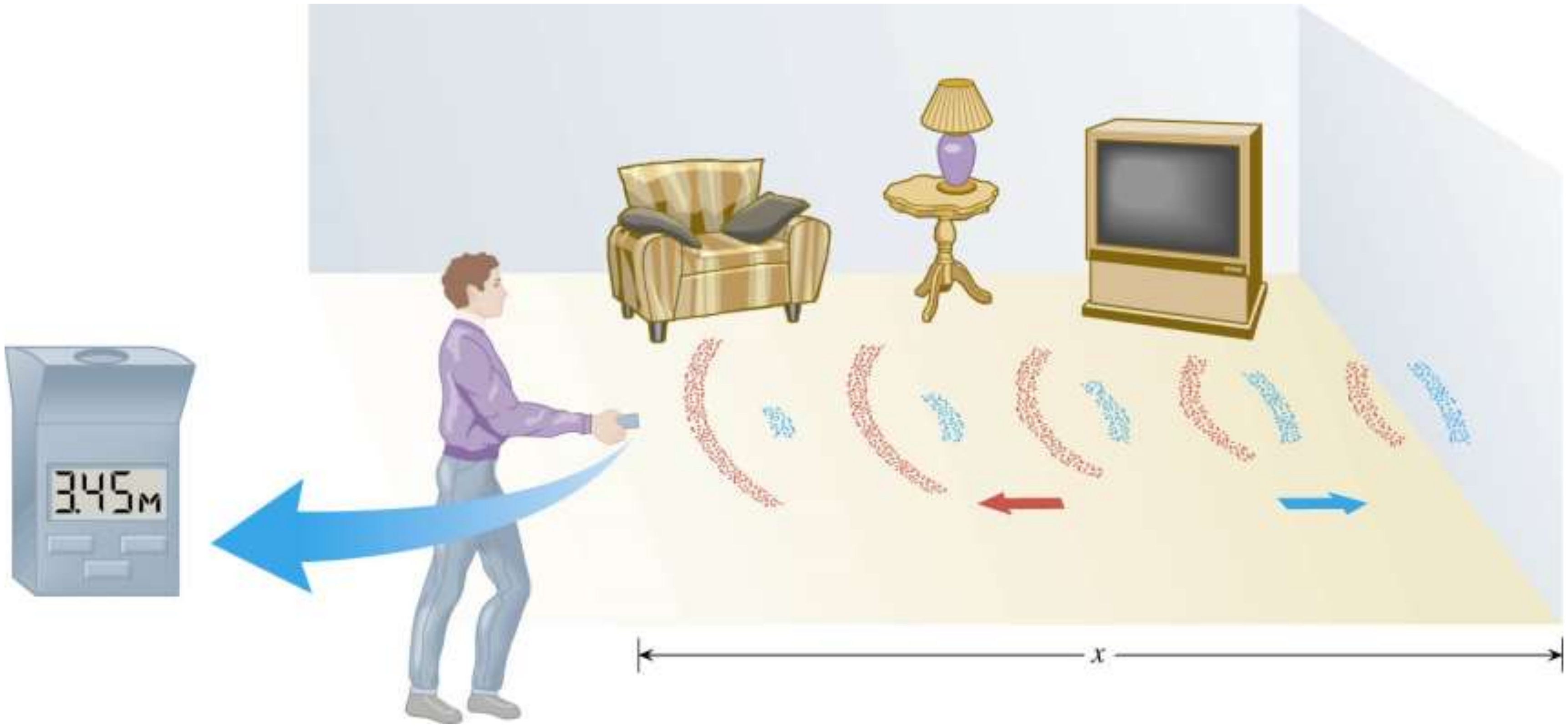
Substance	Speed (m/s)
Solids	
Copper	**5010**
Glass (Pyrex)	**5640**
Lead	**1960**
Steel	**5960**

$$v_{rms} = \sqrt{3kT/m}$$

y=C_P / C_V

Ideal gas $$v = \sqrt{\frac{\gamma k T}{m}}$$

Example 4. An Ultrasonic Ruler



An ultrasonic ruler that is used to measure the distance between itself and a target, such as a wall. To initiate the measurement, the ruler generates a pulse of ultrasonic sound that travels to the wall and, like an echo, reflects from it. The reflected pulse returns to the ruler, which measures the time it takes for the round-trip. Using a preset value for the speed of sound, the unit determines the distance to the wall and displays it on a digital readout. Suppose the round-trip travel time is 20.0 ms on a day when the air temperature is 23 °C. Assuming that air is an ideal gas for which *g* = 1.40 and that the average molecular mass of air is 28.9 u, find the distance *x* to the wall.

T = 23 + 273.15 = 296 K,

1 u = 1.6605 × 10^{-27} kg

$$m = (28.9\,\text{u})\left(\frac{1.6605\times10^{-27}\ \text{kg}}{1\ \text{u}}\right) = 4.80\times10^{-26}\ \text{kg}$$

$$v = \sqrt{\frac{\gamma kT}{m}} = \sqrt{\frac{(1.40)(1.38\times10^{-23}\ \text{J/K})(296\ \text{K})}{4.80\times10^{-26}\ \text{kg}}} = 345\ \text{m/s}$$

$$x = vt = (345\ \text{m/s})(10.0\times10^{-3}\ \text{s}) = \boxed{3.45\ \text{m}}$$

Check Your Understanding

Carbon monoxide (CO), hydrogen (H2), and nitrogen (N2) may be treated as ideal gases. Each has the same temperature and nearly the same value for the ratio of the specific heat capacities at constant pressure and constant volume. In which two of the three gases is the speed of sound approximately the same?

CO & N_2

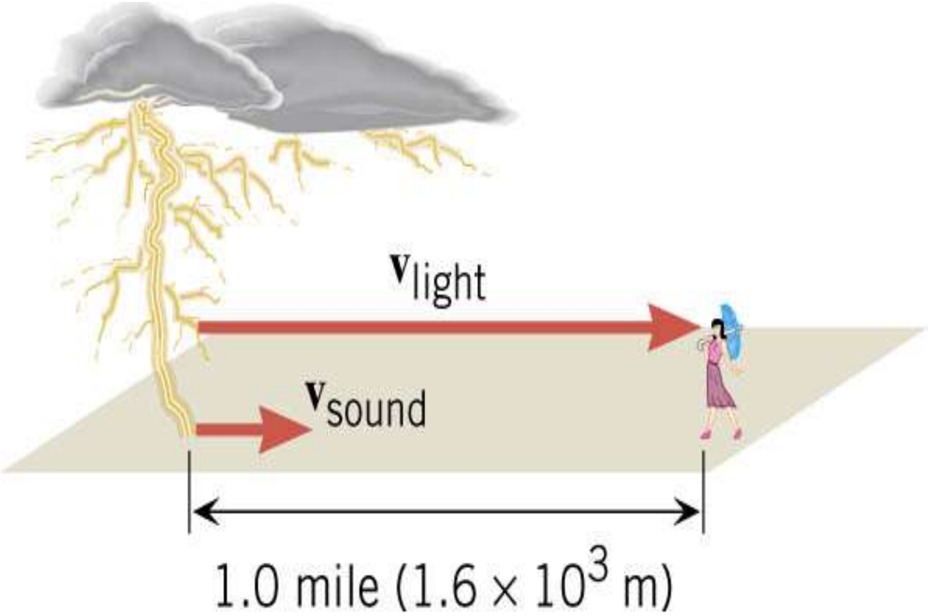
Conceptual Example 5. Lightning, Thunder, and a Rule of Thumb

There is a rule of thumb for estimating how far away a thunderstorm is. After you see a flash of lightning, count off the seconds until the thunder is heard. Divide the number of seconds by five. The result gives the approximate distance (in miles) to the thunderstorm. Why does this rule work?

Speed of light= 3.0 $*10^8$ m/s .

Time for the lightning bolt to travel 1 mile = 1.6 $*10^3 * 3 * 10^8$ m/s = 5.3 $*10^{-6}$, i.e. 5 micro seconds.

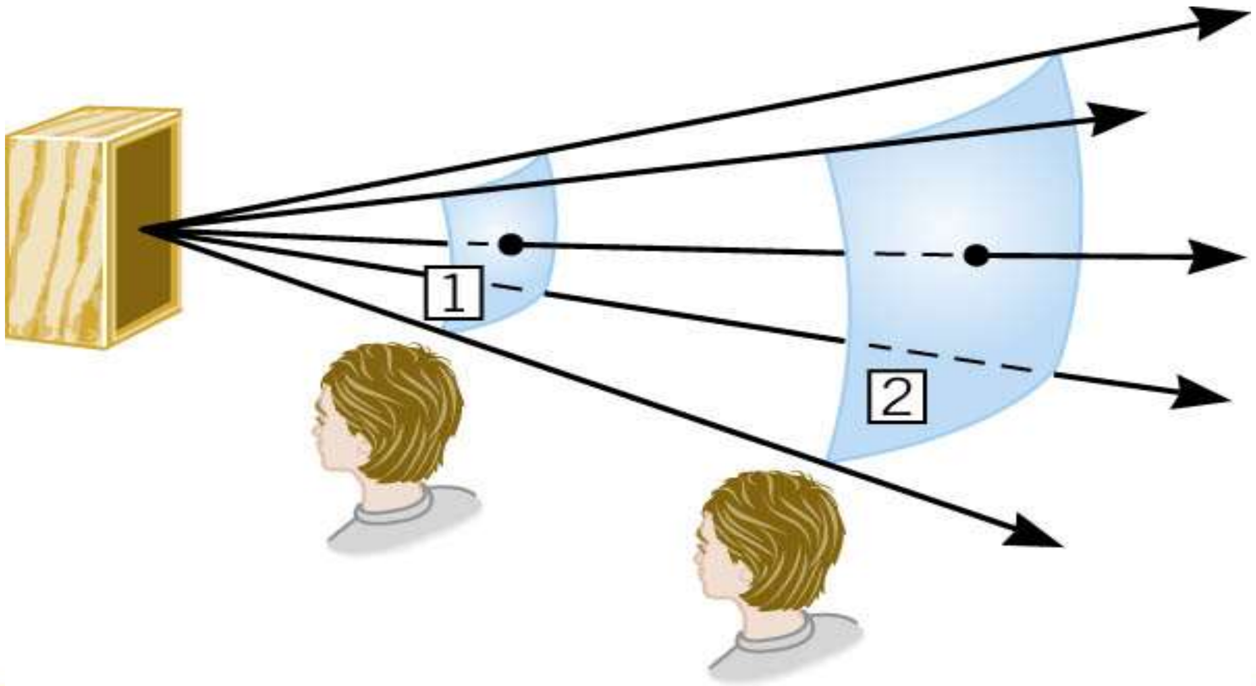
Time for the sound to travel one mile (1.6 $* 10^3$ m) = 1.6 $* 10^3 *$ 343 m/s = 5 sec.

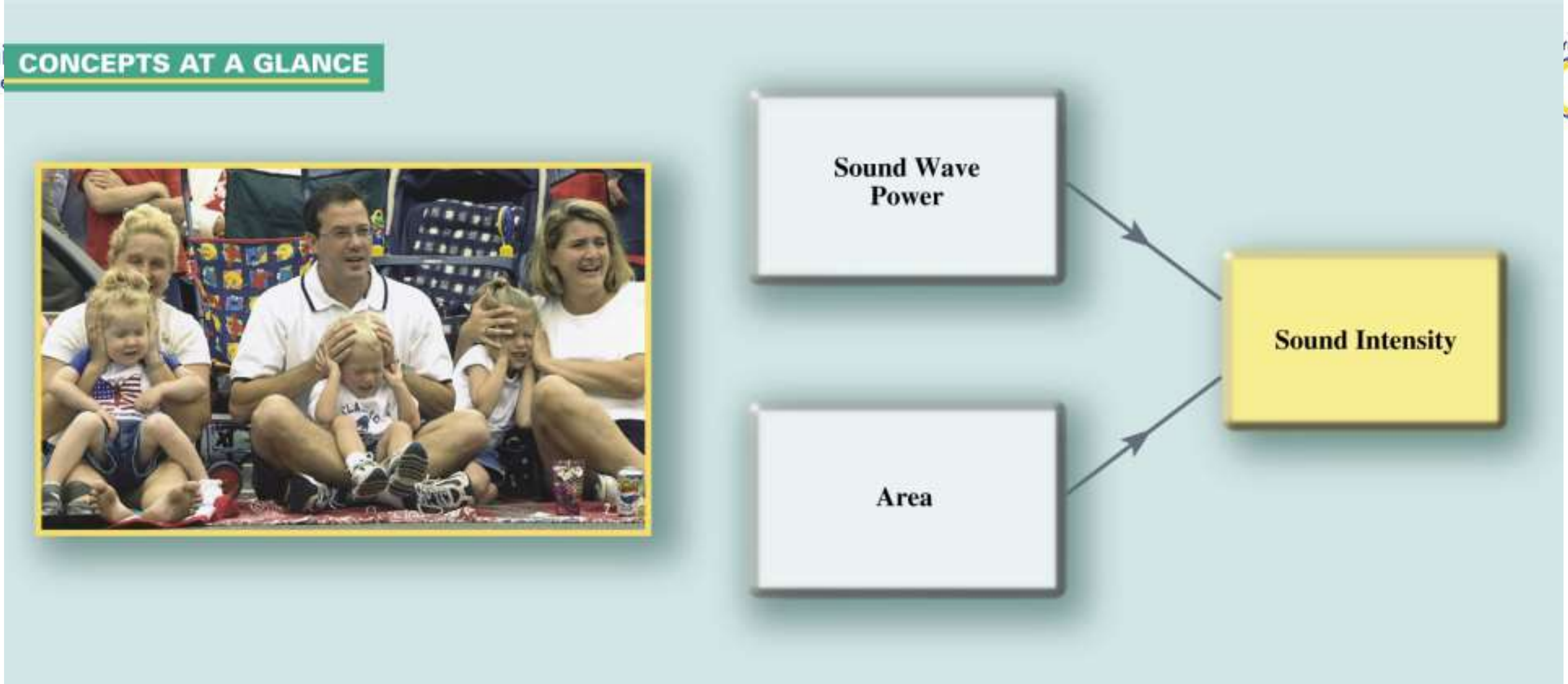


This rule of thumb works because the speed of light is so much greater than the speed of sound.

Sound Intensity

The amount of energy transported per second by a sound wave is called the *power* of the wave and is measured in SI units of joules per second (J/s) or watts (W).





The ***sound intensity*** ***I*** **is defined as the sound power** ***P*** **that passes perpendicularly through a surface divided by the area** ***A*** **of that surface:**

$$I = \frac{P}{A}$$

Unit of sound intensity is power per unit area, or W/m^2

Example 6. Sound Intensities

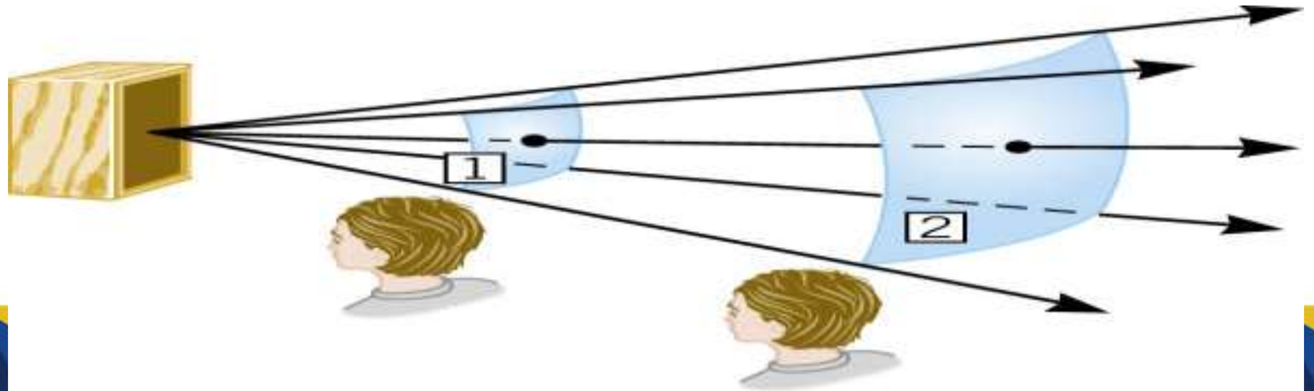
12×10^{-5} W of sound power passes perpendicularly through the surfaces labeled 1 and 2. These surfaces have areas of A_1 = 4.0 m^2 and A_2 = 12 m^2. Determine the sound intensity at each surface and discuss why listener 2 hears a quieter sound than listener 1.

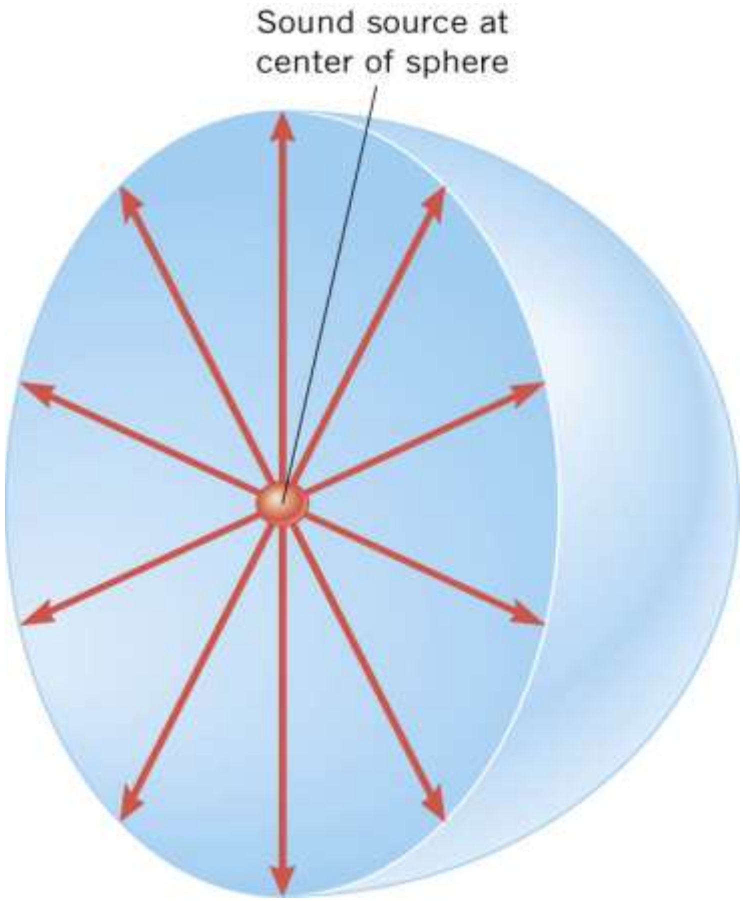
Surface 1

$$I_1 = \frac{P}{A_1} = \frac{12\times10^{-5}\text{ W}}{4.0\text{ m}^2} = \boxed{3.0\times10^{-5}\text{ W/m}^2}$$

Surface 2

$$I_2 = \frac{P}{A_2} = \frac{12\times10^{-5}\text{ W}}{12\text{ m}^2} = \boxed{1.0\times10^{-5}\text{ W/m}^2}$$



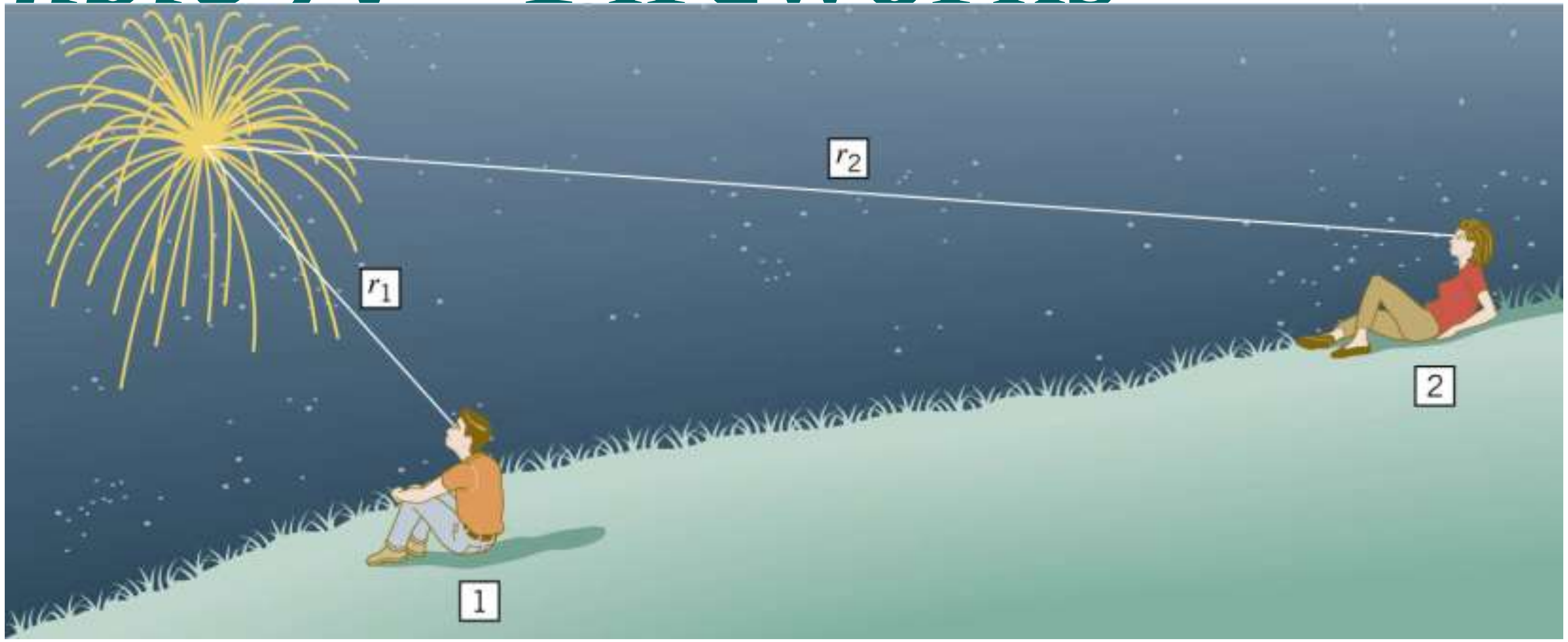


The sound source at the center of the sphere emits sound uniformly in all directions.

Spherically uniform radiation

$$I = \frac{P}{4\pi r^2}$$

Example 7. Fireworks



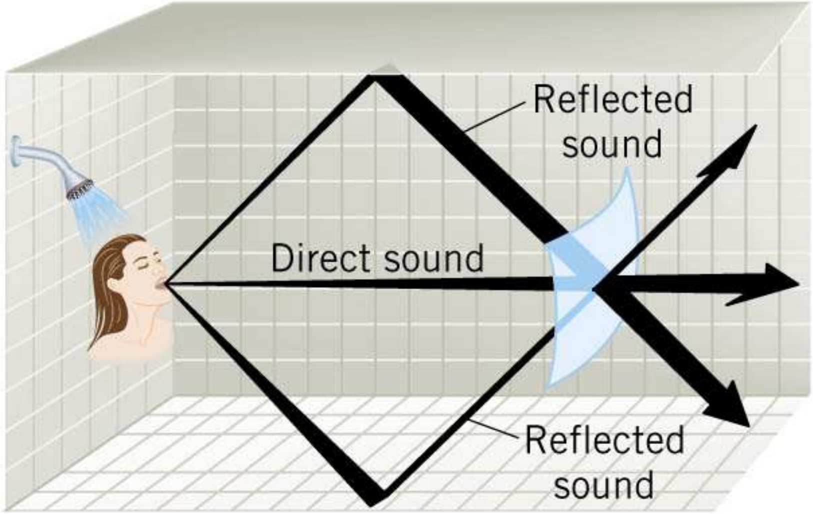
A rocket explodes high in the air. Assume that the sound spreads out uniformly in all directions and that reflections from the ground can be ignored. When the sound reaches listener 2, who is r_2 = 640 m away from the explosion, the sound has an intensity of I_2 = 0.10 W/m^2. What is the sound intensity detected by listener 1, who is r_1 = 160 m away from the explosion?

$$\frac{I_1}{I_2} = \frac{\dfrac{P}{4\pi r_1^2}}{\dfrac{P}{4\pi r_2^2}} = \frac{r_2^2}{r_1^2} = \frac{(640\ \text{m})^2}{(160\ \text{m})^2} = 16$$

$$I_1 = (16)I_2 = (16)(0.10\ \text{W/m}^2) = \boxed{1.6\ \text{W/m}^2}$$

Conceptual Example 8. Reflected Sound and Sound Intensity

Suppose the person singing in the shower produces a sound power *P*. Sound reflects from the surrounding shower stall. At a distance *r* in front of the person, does Equation 16.9, $I = P/(4\pi r^2)$, underestimate, overestimate, or give the correct sound intensity?



The relation underestimates the sound intensity from the singing because it does not take into account the reflected sound.

Decibels

***Decibel* (dB)** **is a measurement unit used when comparing two sound intensities.**

Intensity level

$$\beta = (10\,\text{dB})\log\left(\frac{I}{I_0}\right)$$

$$\beta = (10\,\text{dB})\log\left(\frac{8\times10^{-12}\,\text{W/m}^2}{1\times10^{-12}\,\text{W/m}^2}\right) = (10\,\text{dB})\log 8 = (10\,\text{dB})(0.9) = 9\,\text{dB}$$

If $I = I_0$

$$\beta = (10\,\text{dB})\log\left(\frac{I_0}{I_0}\right) = (10\,\text{dB})\log 1 = 0$$

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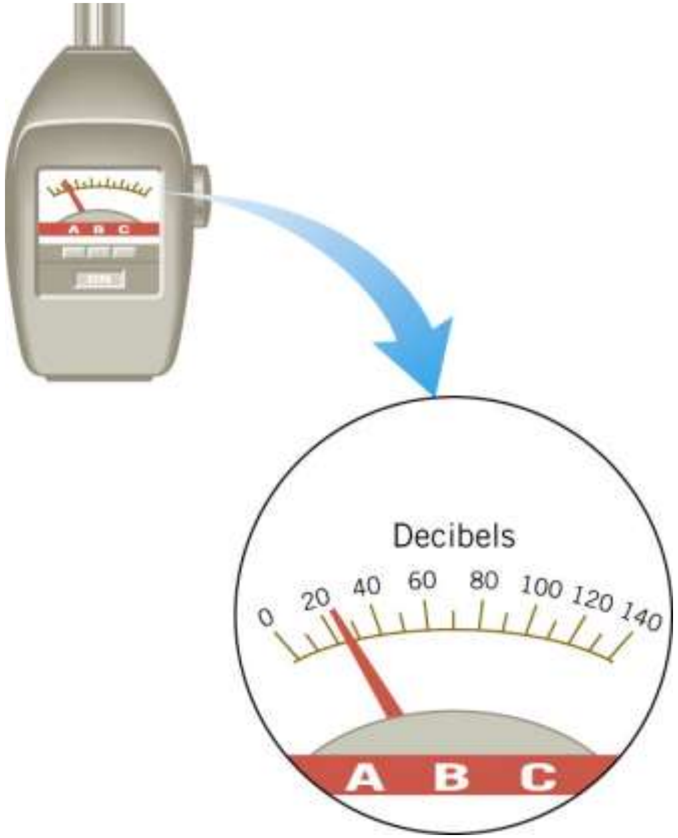
Intensity levels can be measured with a sound level meter.



	Intensity I (W/m^2)	Intensity Level β (dB)
Threshold of hearing	1.0×10^{-12}	0
Rustling leaves	1.0×10^{-11}	10
Whisper	1.0×10^{-10}	20
Normal conversation (1 meter)	1.0×10^{-6}	65
Inside car in city traffic	1.0×10^{-4}	80
Car without muffler	1.0×10^{-2}	100
Live rock concert	1.0	120
Threshold of pain	10	130

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Greater intensities give rise to louder sounds. However, the relation between intensity and loudness is not a simple proportionality, because doubling the intensity does not double the loudness.

Hearing tests have revealed that a one-decibel (1-dB) change in the intensity level corresponds to approximately the smallest change in loudness that an average listener with normal hearing can detect.

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Example 9. Comparing Sound Intensities

Audio system 1 produces an intensity level of β_1 = 90.0 dB, and system 2 produces an intensity level of β_2 = 93.0 dB. The corresponding intensities (in W/m^2) are I_1 and I_2. Determine the ratio I_2/I_1.

$$\beta_2 - \beta_1 = (10\,\text{dB})\log\left(\frac{I_2}{I_0}\right) - (10\,\text{dB})\log\left(\frac{I_1}{I_0}\right) = (10\,\text{dB})\log\left(\frac{I_2/I_0}{I_1/I_0}\right)$$

$$= (10\,\text{dB})\log\left(\frac{I_2}{I_1}\right)$$

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Solution Using the result just obtained, we find

$$93.0\,\text{dB} - 90.0\,\text{dB} = (10\,\text{dB})\log\left(\frac{I_2}{I_1}\right)$$

$$0.30 = \log\left(\frac{I_2}{I_1}\right) \quad \text{or} \quad \frac{I_2}{I_1} = 10^{0.30} = \boxed{2.0}$$

Doubling the intensity changes the loudness by only 3 decibels (not doubled)

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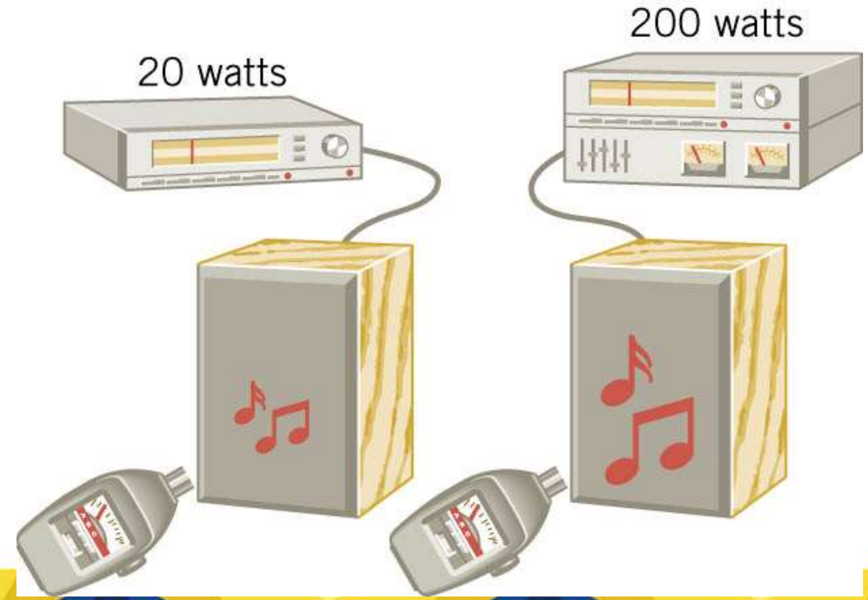
Experiment shows that if the intensity level increases by 10 dB, the new sound seems approximately twice as loud as the original sound.

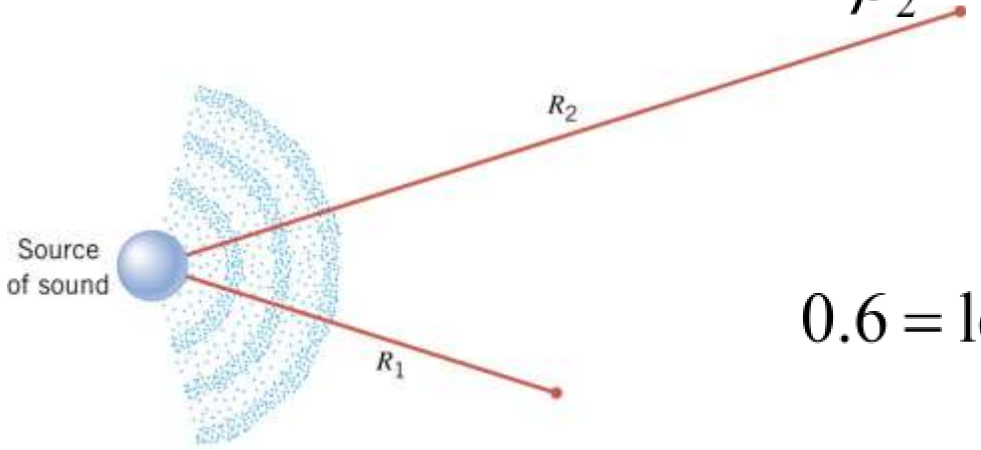
$$\beta_2 - \beta_1 = 10.0\,\text{dB} = (10\,\text{dB})\left[\log\left(\frac{I_2}{I_0}\right) - \log\left(\frac{I_1}{I_0}\right)\right]$$



Check Your Understanding

The drawing shows a source of sound and two observation points located at distances R_1 and R_2. The sound spreads uniformly from the source, and there are no reflecting surfaces in the environment. The sound heard at the distance R_2 is 6 dB quieter than that heard at the distance R_1. (a) What is the ratio I_2/I_1 of the sound intensities at the two distances? (b) What is the ratio R_2/R_1 of the distances?

$$\beta_2 - \beta_1 = (10\ \text{dB}) \log\left(\frac{I_2}{I_1}\right)$$



$$6dB = 10dB \cdot Log\left(\frac{I_1}{I_2}\right)$$

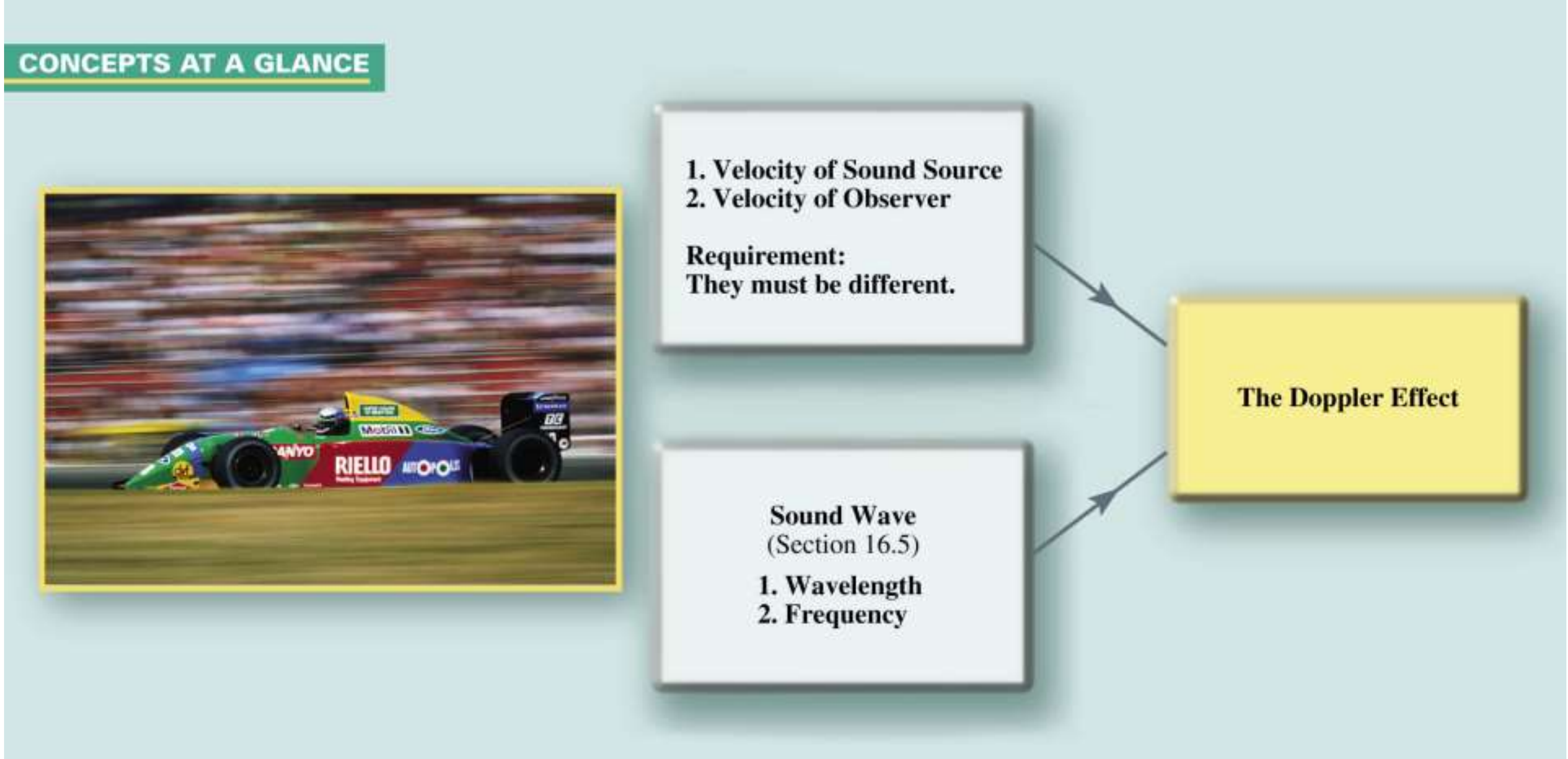
$$0.6 = \log\left(\frac{I_1}{I_2}\right) \qquad 10^{0.6} = \frac{I_1}{I_2} = 4$$

$$\frac{I_2}{I_1} = \frac{1}{4}$$

(a) 1/4 (b) 2

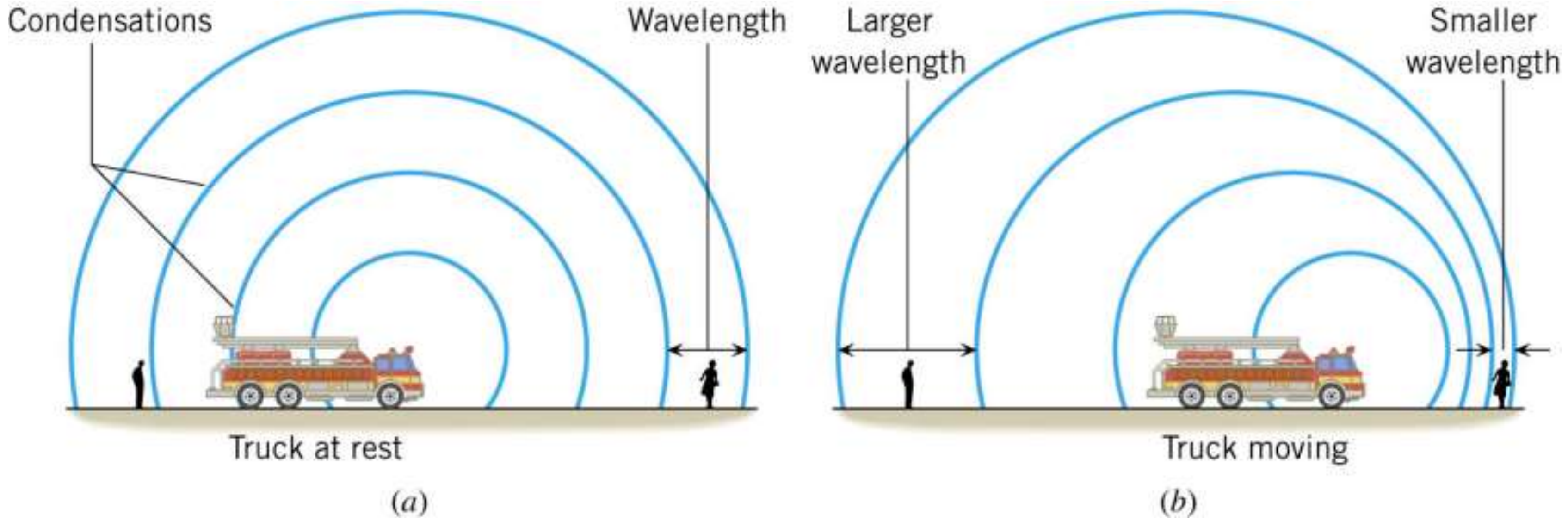
$$I = P / 4\pi R^2$$

The Doppler Effect



Moving Source

(*a*) When the truck is stationary, the wavelength of the sound is the same in front of and behind the truck. (*b*) When the truck is moving, the wavelength in front of the truck becomes smaller, while the wavelength behind the truck becomes larger.



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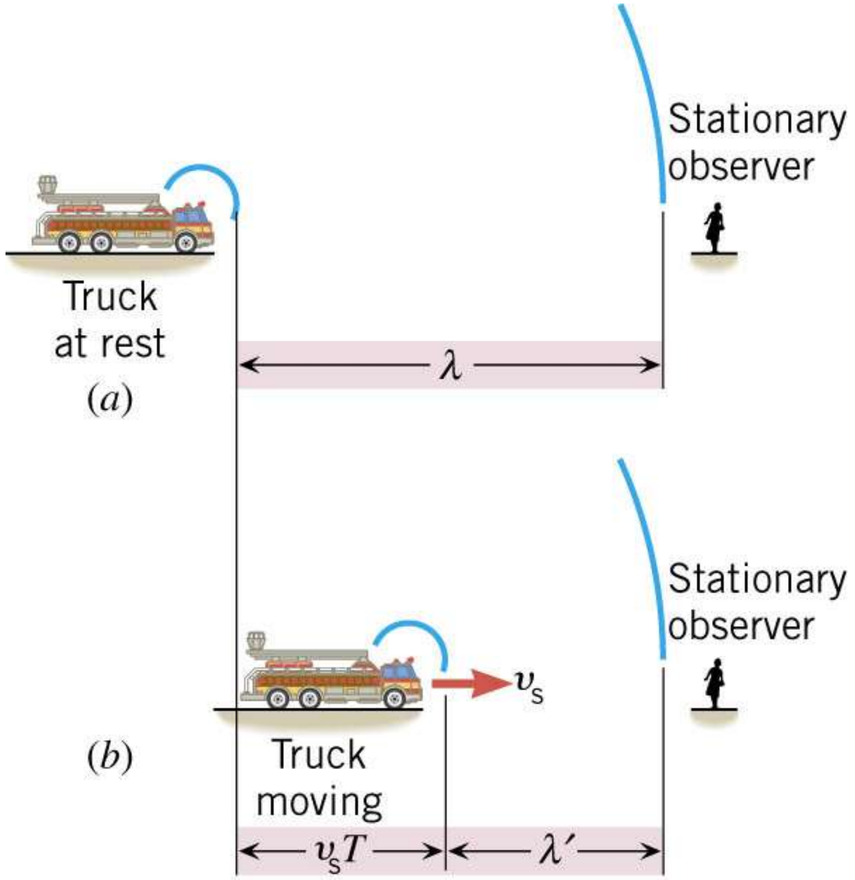


(a) When the fire truck is stationary, the distance between successive condensations is one wavelength λ.

(b) When the truck moves with a speed v_s, the wavelength of the sound in front of the truck is shortened to λ'.

$$\lambda' = \lambda - v_s T$$

$$f_o = \frac{v}{\lambda'} = \frac{v}{\lambda - v_s T}$$

Source moving toward stationary observer

$$f_o = f_s \left(\frac{1}{1 - \frac{v_s}{v}} \right)$$

$$\lambda' = \lambda + v_s T$$

Source moving away from stationary observer

$$f_o = f_s \left(\frac{1}{1 + \frac{v_s}{v}} \right)$$

Example The Sound of a Passing Train

A high-speed train is traveling at a speed of 44.7 m/s (100 mi/h) when the engineer sounds the 415-Hz warning horn. The speed of sound is 343 m/s. What are the frequency and wavelength of the sound, as perceived by a person standing at a crossing, when the train is (a) approaching and (b) leaving the crossing?

(a) $$f_o = f_s\left(\frac{1}{1-\frac{v_s}{v}}\right) = (415\,\text{Hz})\left(\frac{1}{1-\frac{44.7\,\text{m/s}}{343\,\text{m/s}}}\right) = \boxed{477\,\text{Hz}}$$

$$\lambda' = \frac{v}{f_o} = \frac{343\,\text{m/s}}{477\,\text{Hz}} = \boxed{0.719\,\text{m}}$$

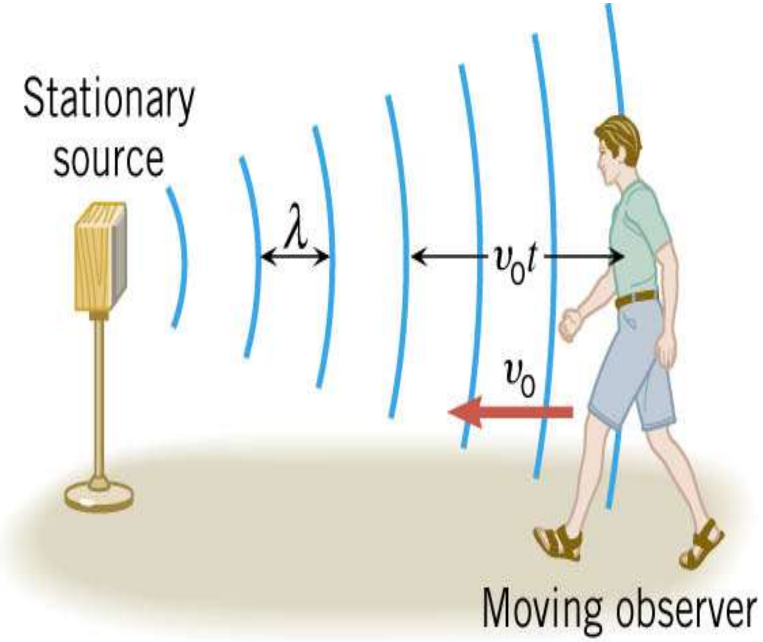
(b)

$$f_o = f_s\left(\frac{1}{1+\frac{v_s}{v}}\right) = (415\,\text{Hz})\left(\frac{1}{1+\frac{44.7\,\text{m/s}}{343\,\text{m/s}}}\right) = \boxed{367\,\text{Hz}}$$

$$\lambda' = \frac{v}{f_o} = \frac{343\,\text{m/s}}{367\,\text{Hz}} = \boxed{0.935\,\text{m}}$$

Moving Observer

$$f_O = f_S + \frac{v_O}{\lambda} = f_S\left(1 + \frac{v_O}{f_S\lambda}\right)$$



Observer moving toward stationary source

$$f_O = f_S\left(1 + \frac{v_O}{v}\right)$$

Observer moving away from stationary source

$$f_O = f_S\left(1 - \frac{v_O}{v}\right)$$

General Case

Source and observer both moving

$$f_O = f_S \left(\frac{1 \pm \frac{v_O}{v}}{1 \mp \frac{v_S}{v}} \right)$$

Check Your Understanding

When a truck is stationary, its horn produces a frequency of 500 Hz. You are driving your car, and this truck is following behind. You hear its horn at a frequency of 520 Hz.

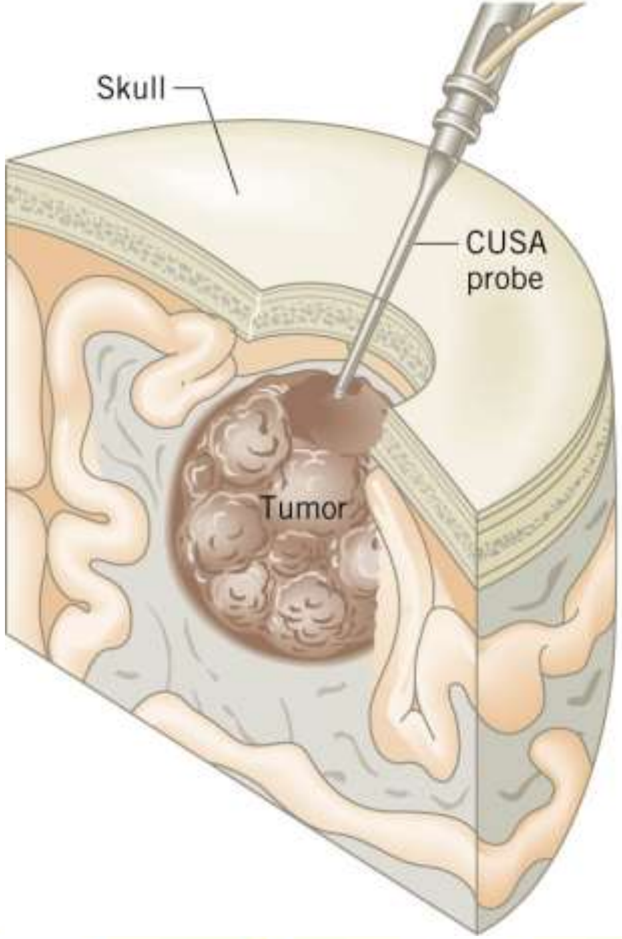
(a) Who is driving faster, you or the truck driver, or are you and the truck driver driving at the same speed?

(b) Refer to Equation 16.15 and decide which algebraic sign is to be used in the numerator and which in the denominator.

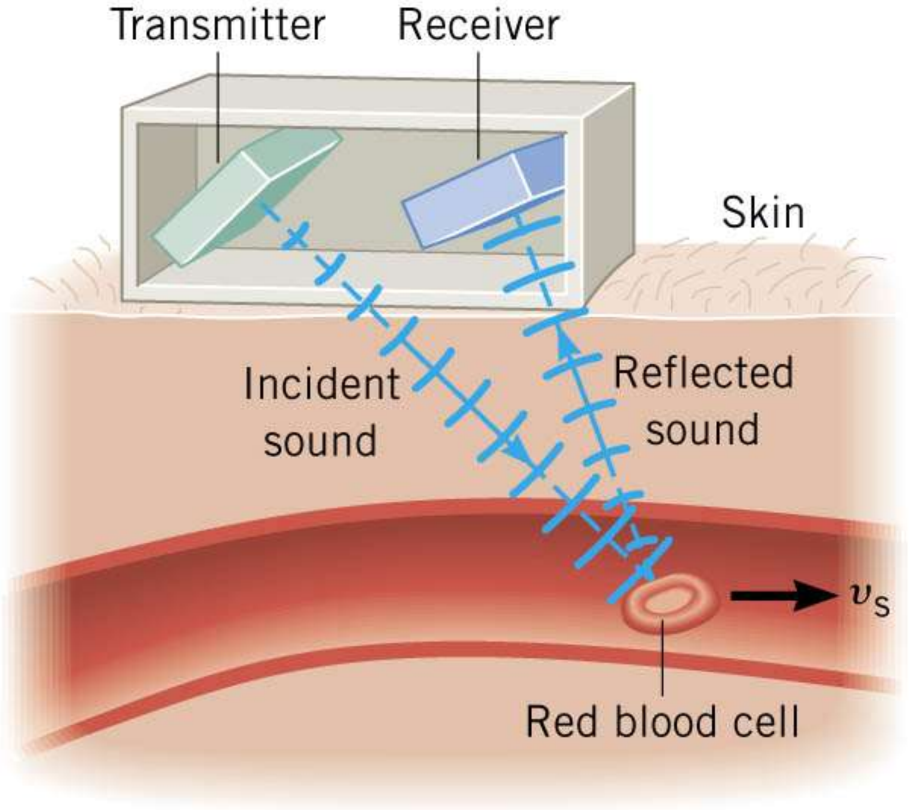
(a) The truck driver is driving faster.

(b) Minus sign in both places.

Applications of Sound in Medicine

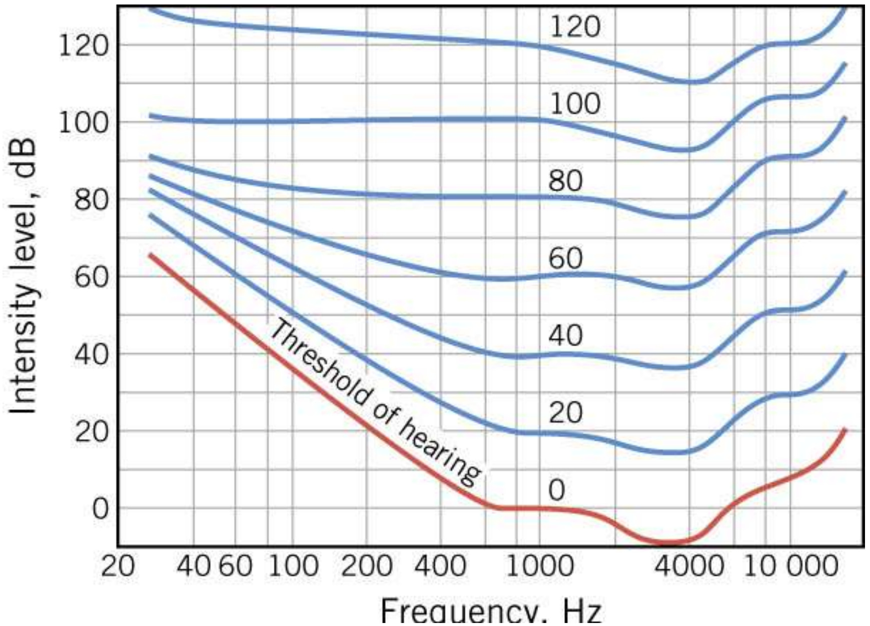


Neurosurgeons use a cavitron ultrasonic surgical aspirator (CUSA) to “cut out” brain tumors without adversely affecting the surrounding healthy tissue.



A Doppler flow meter measures the speed of red blood cells

The Sensitivity of the Human Ear



Each curve represents the intensity levels at which sounds of various frequencies have the same loudness. The curves are labeled by their intensity levels at 1000 Hz and are known as the Fletcher–Munson curves.

Reflection

- Sound can be reflected by hard surfaces or absorbed by soft surfaces.

- The quality of the wall, ceiling, and floor surfaces of a room or studio will determine the way a sound can be reproduced.

Applications of Sound

EQ: How are sound reflections and ultrasound used in daily life?

Reflection of Sound Waves

- Occurs when a sound wave cannot pass through an object, the wave bounces back, or is reflected .
- A reflected sound is called an echo

EQ: How are sound reflections and ultrasound used in daily life?

Vocabulary

- Sonar – a system of detecting reflected sound waves used to determine
  - Depth of the water
  - Locate a sunken ship or cargo
  - Locate boats on the ocean
- Sonar stands for sound navigation and ranging
  - Navigation means finding your way
  - Ranging means finding the distance between two objects

EQ: How are sound reflections and ultrasound used in daily life?

Sonar

EQ: How are sound reflections and ultrasound used in daily life?

- How does sonar work?

1. Sonar machine, or depth finder, produces a burst of high frequency ultrasonic sound waves that travel through water
2. The waves hit an object or the ocean floor, then they reflect back
3. The sonar device measures the time it takes to detect the reflected sound wave
4. The intensity of the reflected waves tells the size and the shape of the object

Ultrasound and Infrasound

Ultrasonic waves are sound waves higher than a human can hear

Infrasonic waves are sound waves lower than a human can hear

Echolocation- the use of sound waves to determine distance or to locate objects

EQ: How are sound reflections and ultrasound used in daily life?

Ultrasound in the Ocean

- Dolphins and whales use echolocation to identify prey and to find their way
- Fishermen attach ultrasonic beepers to their nets to keep dolphins away from their catch
- People wear ultrasonic beepers to keep sharks away when they dive

Ultrasound in Medicine

- Sonograms – ultrasound doctors use to get a picture of something inside the body

EQ: How are sound reflections and ultrasound used in daily life?

Ultrasound at home

- Ultrasonic toothbrushes – sound can reach into places the bristles cannot, cleaning your teeth better
- Jewelry cleaner – sound vibrations shake dirt off your jewelry without causing damage
- Auto focus camera – uses ultrasound to find the distance of an object

Resonance of Sound

- Any oscillating object has a *natural frequency,* which is the frequency an oscillating object tends to settle into if it is not disturbed.

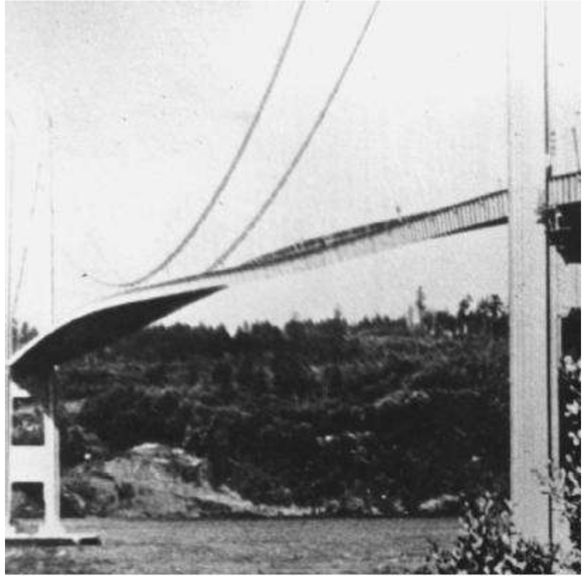
- The phenomenon in which a relatively small, repeatedly applied force causes the amplitude of an oscillating system to become very large is called *resonance*

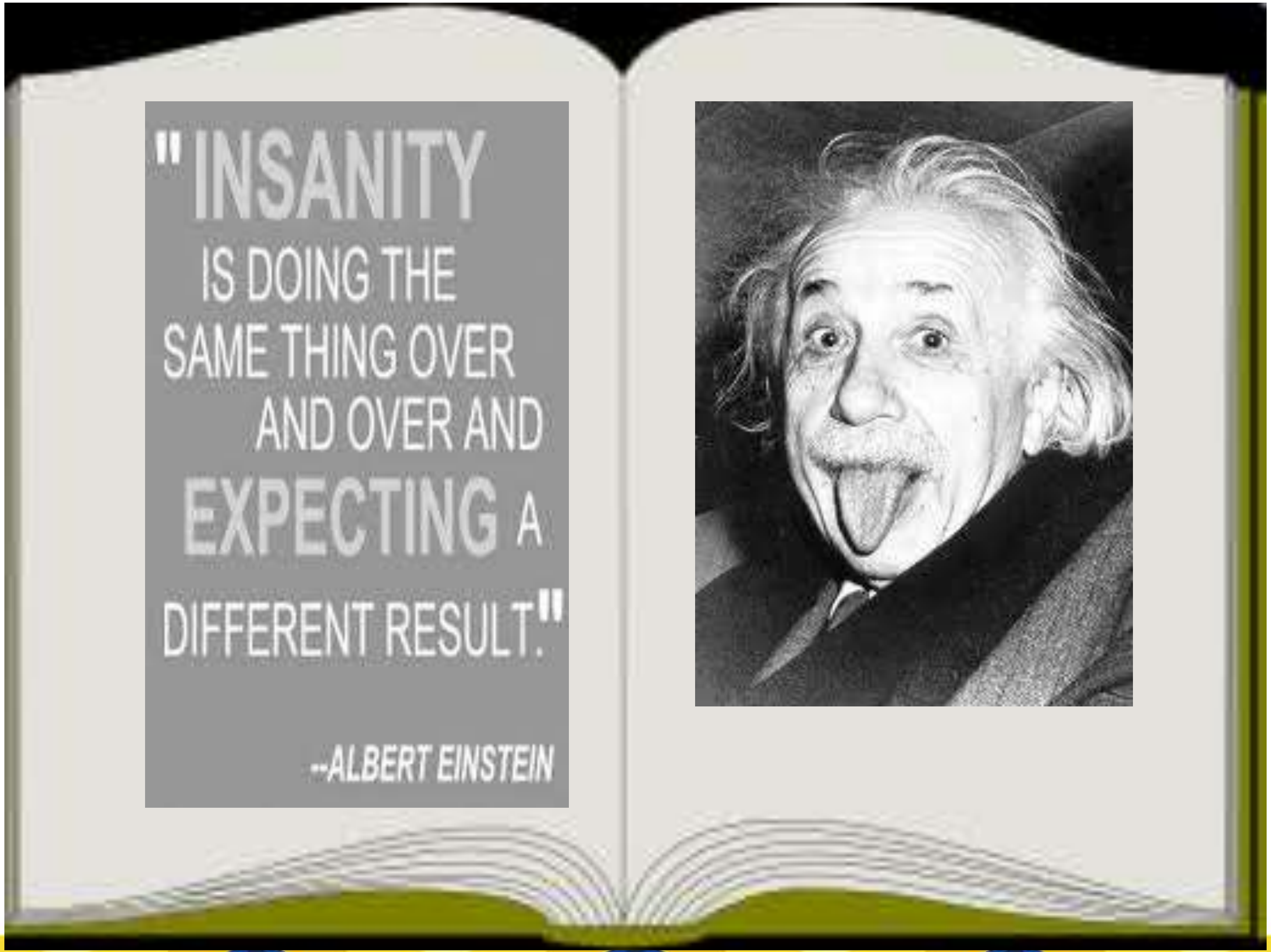
Sound Waves

Sound Waves are a common type of standing wave as they are caused by RESONANCE.

Resonance – when a FORCED vibration matches an object's natural frequency thus producing vibration, sound, or even damage.

One example of this involves shattering a wine glass by hitting a musical note that is on the same frequency as the natural frequency of the glass. (Natural frequency depends on the size, shape, and composition of the object in question.) Because the frequencies resonate, or are in sync with one another, maximum energy transfer is possible.




"INSANITY
IS DOING THE
SAME THING OVER
AND OVER AND
EXPECTING A
DIFFERENT RESULT."
--ALBERT EINSTEIN